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ON THE FUNCTIONS OF THE CEREBRUM
THE FRONTAL LOBES

BY

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PREFACE.

The present article is intended to be one of a series dealing with the functions of different parts of the cerebrum, more particularly with the so-called association areas. The publication of the present work has been considerably delayed, owing to the pressure of other duties, but it is hoped that the second article of the series, dealing with the parieto-occipito-temporal association area, will be ready soon.

The experiments contained in this monograph were made at three institutions: The Harvard Medical School, the Dartmouth Medical School, and the McLean Hospital. I am under obligation to the officers of these institutions for assistance and advice in many ways.

An account of the experiments on cats has been previously reported in the *American Journal of Physiology,* and for permission to republish part of this work I am indebted to the editor, Dr. W. T. Porter.

A grant from the Carnegie Institution to the author, as research assistant, made it possible to continue the investigation of the functions of the association areas, and to extend the work to include experiments upon monkeys. I take this opportunity to acknowledge the aid thus rendered and to express my sense of obligation for it.

Shepherd Ivery Franz.

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I. INTRODUCTION AND HISTORICAL

Aside from philosophical speculation the brain is generally admitted to be the part of the body most intimately associated with the mental life. In popular terms, it is the "seat of the mind." This view has been held and advocated for several centuries, but not until about fifty years ago did it receive universal acceptance. At different times, by different schools or individuals, attempts were made to locate in the cerebrum, cerebellum or mid-brain certain mental processes and to mark off accurately the part or parts of the nervous system concerned with definite psychological states.[1]

The methods which have been employed in these attempts may be briefly designated as anatomical, physiological and clinico-pathological. By careful dissections anatomists have been able to determine the distribution of nerves to the muscles, skin and other organs, and often to trace the paths of groups of nerve fibers within, as well as without, the central nervous system. From these studies inferences may be drawn regarding the functions of different parts of the spinal cord, cerebellum, mid-brain and cerebrum. The special methods of physiological research are those of stimulation and extirpation. By electrical or other stimulation of portions of the nervous system in animals chiefly motor and vascular reactions are obtained. These results are of the highest value for a proper interpretation of function, particularly when they are combined with the effects or functional losses that follow experimental ablations and destructions. By itself the extirpation method is valuable chiefly by reason of its applicability to regions of the cerebrum which are not excitable, or, rather, which do not produce noticeable effects upon stimulation. Clinico-pathological and neurological investigators have been able to study in man the effects of destructions, from accidents and neoplasms, and of disturbances of function, from emboli, thrombi and hemorrhages, of parts of the brain; and their examinations have been most valuable in that the results were obtained from man. It can hardly be doubted that the accidental nature of the brain lesions in man limits the application of the method, and Ferrier has urged, probably too strongly, that the results of clinical inquiries are valuable mainly as confirmations of the stimulation and extirpation methods of the physiologists.[1] In the attempts to determine the relation of the brain to the so-called higher mental processes, it appears to me that the observations of the effects of cerebral disease and injury in man are of greater potential value than hundreds of experiments on animals.[2] The faculty of speech alone makes it possible to acquire information regarding the presence or absence of associational ability, and the speech losses and disturbances are in themselves psychical association disorders which have been most successfully investigated. [redacted]

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[1] An excellent account of the historical development of ideas regarding the cerebrum will be found in an article by Soury in Richet: *Dictionnaire de Physiologie*, II., pp. 547–670. For some of the matter of this section the author is indebted to Soury's work.

The history of the localization of brain functions is made up of contradictory results, recrimination and speculation. Philosophers and theologians combatted the attempts to understand the workings of the brain, and not until about 1860 did belief and dogma give way to a general spirit of investigation.

It is to Gall and Spurzheim that we owe the lively interest of the French of fifty years ago and of their successors in the localization of the functions of the cerebrum. Clinical and pathological observations, physiological experiments and careful dissections were the foundations of their ideas. For them the mind was not a simple thing but an aggregation of different faculties, and they did not hold with earlier writers that it could not exist in space, but was determinable solely in time. "There are as many different systems (in the brain and other parts of the central nervous system) as there are different functions. Each system of the animal life is double. These double systems are united by means of commissures. In virtue of all this, there does not and can not exist any common centre for all our sensations, all our thoughts and all our actions, and finally the unity of the ego will always remain a mystery."[3] In their system of phrenology the authors attempted a correlation between the shape of the head and certain intellectual states, but they were careful, particularly in their earlier publications, to point out that the correlation was really between brain shape and mental conditions. The form of the cranium, they said, is determined by the underlying brain and in the latter the moral and intellectual qualities have their seats. The head and its bones indicate only the degree of development of the cerebrum and cerebellum. The term physiognomy (phrenology being a branch of physiognomy) "is used to imply a knowledge of the external signs which imply internal qualities."[1] The attempts at a mental and physical correlation were, we now know, based upon a false anatomy of mind. The observations contained in their anatomical books are most valuable and far ahead of the times in which they lived. The greatest value that is to be attached to their work, however, is not that they gathered and reported facts but that their work aroused interest in brain anatomy and physiology, and produced much opposition, discussion, and, consequently, thought in their contemporaries and in later generations.

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[1] *Functions of the Brain*, London, 1886, p. 270.

[2] I have previously pointed out that most of the results adduced by clinicians to support the view of the seat of the 'intellectual faculties' in the frontal lobes are inconclusive. *Journal of the Amer. Med. Assn.*, **47**: 1464–1467, 1906. See also Section II., pp. 23ff of the present article.

[3] F. J. Gall et G. Spurzheim, *Recherches sur le système nerveux en générale, et sur celui du cerveau en particulier*, Paris, 1809, pp. viii + 278. The above conclusions are found on p. 168.

Twenty years later Rolando published an observation of physiological importance, but the experiment does not seem to have been repeated by him or by his co-workers, and its significance was not understood. This was the electrical stimulation of the cerebrum. He says:[2] "I introduced a wire from a Volta cell into the cerebral hemispheres and placed it now on one point, again on another, while the other pole was applied to different parts of the body. From these experiments repeated on different quadrupeds and on birds, I have obtained only violent contractions, and I observed that these were much greater when the metal conductor penetrated the cerebellum." In the hands of succeeding investigators the application of the electric current produced no noticeable results, and soon the dictum arose that the cerebral cortex is not irritable in the manner that was found to be the case with the nerves, the spinal cord, the medulla and, above all, the cerebellum. We now understand that the negative results may have been due to ill-judged use of the electric current, to hemorrhages or cerebral lacerations during the operation, or to a number of other factors. For a generation—until the time of Hitzig—suitable experimental conditions for the irritation of the cortex by electricity were not obtained, and the medulla and cerebellum were thought to be chiefly concerned in the production and coordination of voluntary movement. This hypothesis received its greatest support from the experiments of Flourens.

The methods of stimulation and extirpation were extended by Flourens to all parts of the nervous system. His experiments yielded results much in accordance with the physiological and philosophical tenets of the times. Some of the early errors were confirmed and strengthened, although many advances were made. Three mental functions are differentiated and given seats in special portions of the nervous system.[1] These functions are, he said, (A) perception and volition, *i. e. intelligence,* (B) receiving and transmitting of impressions, *i. e. sensibility,* and (C) *movement* and coordination of movement. The intellectual and perceptive states are functions of the cerebrum, movement is brought about by the medulla oblongata and the nerves, and coordination of movement is effected by the cerebellum. "The cerebral lobes are not the seat either of the immediate principle of muscular movements, or of the principle that coordinates the movements in walking, jumping, flying, standing." They are the exclusive seat of volition and perception. "There are not different seats for the different mental faculties or for the different perceptions. The faculty of perceiving, of judging, or of wishing a thing resides in the same place as that of perceiving, of judging or of wishing any other." The preservation or the loss of functions of intelligence depends not upon a given point in the cerebral lobes, but upon the degree of general alteration of the lobes, whatever the point or points which are affected. A single cerebral lobe or hemisphere suffices for the complete exercise of intelligence. Many of his conclusions seem to be directed principally against the phrenological systems, and to strengthen his position Flourens had to disregard a number of facts learned since the time of Gall and Spurzheim. These facts were gathered chiefly by clinicians, and they tended to show that there are separate centers in the cerebrum.

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[1] P. 2 of G. Spurzheim, *Phrenology in Connection with the Study of Physiognomy*, Part I, London, 1826, pp. 191. 34 plates.

[2] Saggio sopra la vera struttura del cervello e sopra le funzioni del sistema nervosa. Sperienza sul cervello dei mammiferi. 2nd edit., 1828, p. 183. Quoted by Soury, *Op. cit.*, p. 616.

The work of Lallemand, of Parchappe and of Bouillaud deserves mention in this connection. They developed clinical methods and gathered pathological data which enabled them to point out the relationship of parts of the cerebrum to definite conditions of a mental order. To Parchappe is due the credit of having demonstrated clearly that the gray substance is the 'seat of intelligence, will and sensibility.' Previous to his time the cerebral cortex was believed to be a sort of secretion of the pia mater, and it was not considered functionally related to the underlying white fibrous matter. Lallemand and Bouillaud found that muscular paralyses, the inability to move muscles voluntarily, were accompanied by destructions or disturbances of the cerebrum. The conclusion was evident that the cerebrum is the seat of volition and that the medulla and cerebellum are not concerned chiefly with the initiation of the impulses that produce voluntary bodily movements. Lallemand furthermore noted the fact that in people who were paralyzed and anesthetic in, say, a limb only one portion of the cerebrum was disorganized. His conclusion, which has been advocated in recent years, was that "the sensations are perceived by the same portions of the brain that provoke muscular contractions, because in all cerebral affections the same parts are deprived of movement and feeling."

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[1] Flourens, *Recherches expérimentales sur les propriétés et les fonctions du système nerveux dans les animaux vertébrés*, Paris, 1842.

It was Broca, however, that showed most clearly the great value clinical and pathological observations have in the determination of brain functions. With the possible exception of the work of Hitzig, the publications of Broca gave the greatest impetus towards the localization of cerebral functions. He was the first to fight strongly against the doctrine of Flourens—which was current at that time—that the brain acted as a whole for all mental operations. His greatest contribution was the establishment of a definite relation of the third frontal convolution and part of the temporal lobes to the faculty of speech. From 1861, when Broca described his celebrated cases, the question regarding the brain changed. Soon all were compelled to say with him: "I believe in the principle of localization. I cannot admit that the complicated form of the cerebral hemispheres is a sport of nature.[1] We do not know whether each convolution, considered alone, has a function different to those of neighboring convolutions; concerning this we can make only suppositions. We do know, however, that the totality of the convolutions does not constitute a single organ, but many organs or many groups of organs, and that there are in the cerebrum large discrete regions corresponding to large discrete mental functions." The doctrine of Gall and Spurzheim was defended and vindicated, and faith in the views of Flourens was shaken. The clinico-pathological studies which followed Broca's lead seemed to confirm the contentions he made, but it remained for another to complete the overthrow of the older ideas by means of researches carried on in an allied field. From the physiological side Hitzig completed the fight against the conception that the totality of the brain was concerned with every individual idea, sensation or act.

In 1870 Hitzig with Fritsch published the now famous article on the electrical excitability of the cerebrum.[1] Previous to this time the leading opinions and teachings were that the cerebrum, and more especially the cerebral cortex, was inexcitable. Forty years before, it is true, Rolando had found that muscular movements could be produced if one pole of a cell was placed in contact with the cerebrum and the other placed on other parts of the body. We now know that the motor effect produced with this sort of stimulation may have been due to a stimulation of any part of the nerve-muscle apparatus. Few precautions were taken by Rolando to insure solely the galvanization of the cortex or of the cerebral fibrous matter. One of the electrodes in his experiments was placed on parts of the body other than the cerebrum, and it is, therefore, difficult to say whether or not the muscular contractions were due to stimulation of the cerebrum, of the spinal cord, of the nerves or of the muscles. It is probable that the cerebral cortex or the subadjacent fibres were directly stimulated. The experiments of Fritsch and Hitzig were free from this error. Precautions were taken to stimulate, as far as possible, only the cortex, and the results which they obtained were undoubtedly due to the action of the electric current upon the cerebrum. The excitable portion of the dog's cerebrum, they found, is in the anterior region and they attribute the failures of previous investigators to stimulate the cerebrum to the fact that the latter worked upon the posterior lobes. Hitzig, furthermore, confirmed the fact of localization of the motor centers in the dog by extirpating in animals these areas, thus producing paralyses in the corresponding muscles. Two years later Hitzig published[2] an account of a case of abscess of the cerebrum from which he was able to conclude that the motor centers in the dog correspond in position to those in man. Later experiments enabled Hitzig to locate visual perceptive processes in the occipital regions of the cortex. After destruction of the occipital lobes he found that an animal or man becomes blind. The experiments were immediately repeated by many observers, new experimental and clinical facts were reported, old ones were collected. Many objected to Hitzig's interpretation of the data and other explanations were offered, but these will be more profitably discussed when the motor and sensory areas are being considered in detail.[1] Among Hitzig's successors who have contributed most to the solution of the problems by extirpation and stimulation methods may be mentioned Ferrier,[2] Goltz,[3] Horsley,[4] Munk,[5] Schäfer[4] and Sherrington.

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[1] Broca, Sur le siège de la faculté du langage articulé, *Bull. Soc. Anat. de Paris*, 1861, p. 330.

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[1] Ueber die elektrische Erregbarkeit des Grosshirns, *Reichert u. DuBois Reymond's Archiv*, 1870, Heft. 3. The article is reproduced in Hitzig, *Physiologische und klinische Untersuchungen über das Gehirn.*, 1904, Th. 1, pp. 8-35.

[2] Ueber einen interessanten Abscess der Hirnrinde, *Arch. f. Psychiat. u. Nervenkrankheiten*, 3, 231-241, 1872.

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[1] A general account of recent literature on the localization of cerebral functions is given by C. v. Monakow: Ueber den gegenwärtigen Stand der Frage nach der Lokalization im Grosshirn. *Ergebnisse der Physiologie*, I., **2**, 1902, pp. 534–665; III., **2**, 1904, 102–122. v. Monakow gives references to 846 articles, monographs and books.

[2] *Localization of Cerebral Disease*, 1878; *Functions of the Brain*, 2nd Edit., 1886; and numerous researches in the *Proceedings* and *Philosophical Transactions of the Royal Society*, 1874 ff.

[3] *Ueber die Verrichtungen des Grosshirns*, 1881, and articles in *Archiv. f. d. ges. Physiologie* (Pflüger's), 1881 ff.

[4] Articles in *Brain*, in the *Proceedings* and in the *Philosophical Transactions of the Royal Society*, 1886 ff. See also Schäfer's general discussion in his *Text Book of Physiology*, 1900, Vol. II., pp. 697–782.

[5] *Ueber die Functionen der Grosshirnrinde*, 1881; *Ueber die Fuhlsphären der Grosshirnrinde*, 1892–6; *Sehsphäre und Raumvorstellungen*, 1891.

II. CONSIDERATION OF PHYSIOLOGICAL AND CLINICO-PATHOLOGICAL STUDIES OF THE FRONTAL LOBES

"It will be seen that if we mark off upon the surface of the cerebrum the areas from which a response to stimulation is obtainable, and to which we can with some probability ascribe a definitely localized function, whether motor or sensory, a large proportion—relatively much larger in man than in monkey, and becoming progressively smaller in descending the scale of intelligence in mammals—remains over. With regard to these portions of the surface which for the sake of brevity we may speak of as the inexcitable or latent portions, since they are distinguished from the rest by the fact that their excitation produces no obvious response, and their excision no definite paralysis, their function is at present a matter of conjecture."[1] These inexcitable regions have been called by Flechsig the 'association areas,' and they are supposed to be the means of associating the incoming and outgoing impulses and of being the rendezvous of the sensory impulses. Three separate regions have thus been described—the frontal, the parieto-occipital and the insular centers.

From careful microscopic examination of the cell lamination and fiber arrangement in the cortex, with consideration of clinical and physiological data Campbell[2] divides the frontal portion (*i. e.* the portion anterior to the fissure of Rolando and superior to the fissure of Sylvius) of the cerebrum into four distinct sections. The area adjoining the fissure of Rolando—the ascending frontal convolution—Campbell calls the precentral area, having the function of motor control. Anterior to this is an area—the intermediate precentral—which may also be concerned with production of movement. The frontal area comprises in man most of the first and second and a small part of the third frontal convolutions; on the mesial aspect a portion of the cortex lying above the knee of the corpus callosum, and a small area of the orbital lobe. This is distinctly an 'association area.' Anterior to this—at the tip of the frontal lobe—is the prefrontal area. This extends on the mesial surface to the limbic lobe and takes in all the orbital cortex in front of the transverse orbital fissure. This is or may become an association area. Previous investigators have not so carefully divided the frontal region, and in the consideration of results on the frontal lobes the three anterior areas—prefrontal, frontal and intermediate precentral—have generally been grouped. So far as possible it will be my purpose to consider only the results from the frontal and prefrontal areas and these will usually be grouped.

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[1] Schäfer: *Textbook*, II., p. 769.

[2] A. W. Campbell: *Histological Studies on the Localization of Cerebral Function*, 1905, pp. xix + 360. 29 Pl.

Four functions have been assigned to the frontal lobes—movement, inhibition, attention and association. Munk and Ferrier have reported motor derangements following extirpation of the frontals, and Ferrier has obtained movements on stimulation of the cortex. Schäfer seems inclined, owing to the results obtained by some Italian investigators, to consider the frontals as inhibitory organs, and Ferrier and Langelaan have assigned to these regions the function of 'attention.' Bianchi, Hitzig, Flechsig and many clinical observers think that the 'intellectual processes' have their seat here.

A. The Frontal Lobes as Motor Centers.—Munk has reported[1] that after extirpation of the frontal lobes in dogs the animals show a motor paralysis of the trunk muscles, and an inability to turn to the side of the lesion. The accuracy of these observations has been questioned by all who have worked on the matter outside of Munk's laboratory. Ferrier, Goltz, Horsley and Schäfer and many others failed to find any disturbance of the trunk muscles after extirpation of the frontal region, and Goltz reports a case of a dog in which the animal was able to turn around to obtain meat tied to its tail after both frontals were excised. Ferrier and Goltz are particularly severe in their criticisms of Munk's work, the former asserting that much of Munk's work is untrustworthy, and that in particular his "assertions as to the effects of lesion of the prefrontal region have as little foundation as many others of his utterances on cerebral physiology."[2] In the animals, cats and monkeys, on which I have operated I have not noted any disturbance of the trunk muscles. The cats could jump and turn and the monkeys sat, walked, climbed, etc., as well after the removal of the frontals as before.

Ferrier, however, assigns other motor functions to these portions of the cerebrum. Following extirpations he found transient disturbance of the ability to move laterally the eyes and the head, and in one monkey, in which the frontals "had been almost completely extirpated, and which survived in perfect health for nearly three months after the operation, microscopical examination revealed the existence of descending sclerosis in the innermost or mesial bundles of the internal capsule and foot of the crus cerebri on either side" (p. 398). Similar examination of another animal gave like results and Ferrier concludes that the "frontal centers are concerned with the movements of the head and eyes." Stimulation of the frontal regions gave movements of the head and eyes to the opposite side with dilatation of the pupils. Occasionally, the excitation of the prefrontals brought about movements of the head and eyes but the results in this region were not constant and they may have been due to the spreading of the stimulus. Grünbaum and Sherrington[1] have confirmed some of Ferrier's results. On the brain of a chimpanzee, they mark off an area principally in the second frontal lobe, stimulation of which produced eye movements. This area presented "marked differences of reaction from the motor area of the Rolandic region . . . . . and it seems necessary to distinguish it in a physiological category separate from that." The authors here distinguish physiologically those regions which we have seen Campbell later differentiated through his histological studies. Ferrier thinks the prefrontal cortex functions similar to the frontal, although, as we shall see later, he assigns to it a function other than motor. After extirpation of the frontals and prefrontals in cats and monkeys I have not found any apparent difficulty in moving head and eyes. My observations were made usually not until about twenty-four hours after the operations, and it is possible that in these animals there may have been some slight transitory effects of this character. The heads of my animals were well bandaged after the operations and if the disturbance (so far as head movements are concerned) was slight, it may have escaped me. The cases which I most carefully observed could the day following the ablation of the frontals follow with their eyes the movement of food. One animal, a monkey, had a slight strabismus when bought, and this condition appeared to be aggravated by the operation. It was impossible to measure the degree of the motor defect either before or after the operation, and it is probable that the seeming increase in the strabismus was due to the head bandage.

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[1] *Sitzungsber. Berlin Akad. d. Wiss.*, 1892–1896, and *Op. cit.*

[2] *Functions of the Brain*, p. 400.

B. The Frontal Lobes as Centers of Inhibition.—From the results of the experiments of Fano, Libertini, Oddi and Rendiconti[2] Schäfer regards as possible an inhibitory function for the frontal lobes. After the extirpation of the frontal, and especially of the prefrontal, lobes "the time and intensity of spinal reflexes is stated to become shortened; while on the other hand, stimulation of these regions, and especially of the prefrontal, is said, in the dog, to cause prolongation of latency and diminution in intensity of spinal reflex responses. . . . . Very little effect was got by stimulating the occipital region, and none from the parieto-temporal." Ziehen[1] criticizes the results of Libertini on the ground that the reflex time was not measured and that in the animal during its unoperated condition the average variation in Libertini's experiments was found to be very large. The hypothesis of the inhibitory function of the frontal lobes would account for the restlessness and unceasing activity of those animals from which the frontals had been excised, but many animals do not show this unrest. On the contrary, dogs, cats and monkeys often decome dull, apathetic, indifferent and somnolent after removal of the frontals and these conditions are more likely due to an increased inhibition.

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[1] Observations on the Physiology of the Cerebral Cortex of Some of the Higher Apes, *Proc. Roy. Soc.*, 69: 206–209, 1901.

[2] Referred to by Schäfer, p. 773, from which place the quotation that follows was taken. I have not seen the original articles and in the magazines at my disposal only a short review of Libertini's work is given.

C. The Frontal Lobes as Centers for Attention.—On the basis of a motor theory of attention Ferrier and, apparently, Langelaan and Beyerman explain the results of their investigations. Ferrier found, it will be remembered, that destruction of the frontal lobes produced paralysis for lateral movements of the head and eyes and that occasionally on stimulation of the prefrontal lobes these movements were obtained. After loss of the prefrontals an animal appeared to lose the "power of looking at, or directing the gaze towards, objects which did not fall spontaneously within the field of vision." There was an "aspect of uninterest and stupidity, the absence of that active curiosity which is normally manifested by monkeys, and the mental degradation which seems to depend on the loss of the faculty of attention and all that it implies in the sphere of intellectual operations."[2]

The point of departure of the work by Langelaan and Beyerman[3] was that Winkler had found respiratory and heart rhythm changes when the frontal lobes were stimulated, that attentive states are accompanied by shortening of the time of expiration, which becomes superficial, and by accelerated heart beat, and that in relaxed attention there is a retardation of respiration, with a tendency to deeper expiration, and a slowing of the heart. By destroying in dogs a portion of the cortex near the sigmoid gyrus the authors obtained irregular, retarded respirations, accompanied by deep sighs, for a period of ten or twelve days. Two patients who were operated on in the frontal region of the cerebrum showed irregular respiration following operations. The authors conclude from their cases and operations on animals that the two functions—respiratory and cardiac—are controlled by the cortex at the base of the second frontal convolutions, near the area governing the conjugate movements of the head and eyes. In the reports of the two clinical cases in which operations took place Langelaan and Beyerman do not give the mental condition of the patients before and after the operations, and it should be stated that the conclusion regarding the attention function of the frontal lobes is not explicitly stated in their article. It seems evident, however, that they wish to correlate the respiratory and cardiac phenomena with the process of attention.

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[1] *Neurol. Centralbl.*, **15:** 589–590, 1896.

[2] *Op. cit.*, p. 465.

[3] J. W. Langelaan and D. H. Beyerman, On the Localization of a Respiratory and a Cardio-motor Center in the Cortex of the Frontal Lobe, *Brain*, **26:** 81–93, 1903.

In the work both of Langelaan and of Ferrier movements of attention are confounded with attention itself. With this conception of attention we can readily understand the conclusions which have been drawn from their work. This frontal-lobe-attention hypothesis accounts for the motor derangements, which, we have seen, do not support the 'inhibition' conjecture. On the other hand, several objections may be urged against the attention explanation. In some cases of frontal injury and destruction in man no mental change has been recorded. It may be true that these cases were not well observed, but it would be impossible to have the attention altered without an obvious change in other mental states. Moreover, if the organ which makes attentive states possible were destroyed we should not expect that an animal could acquire new associations or adapt itself to new environments. On the contrary, however, I have found that bilateral as well as unilateral destruction of the frontal lobes does not prevent the acquirement of habits by an animal. This matter will be discussed in more detail in a later section. To sum up it may be said that regardless of any psychological analysis or definition of attention the weight of evidence seems to me to be against considering the frontal lobes solely as attention centers.

D. The Frontal Lobes as Centers for Intellectual States.—The opinion that the frontal lobes are concerned with the so-called higher mental processes has been held by Broca, by Hitzig, and by many others. Much of the physiological and especially the clinical evidence supports this supposition, but there are many negative cases which must be considered.

Four collections of clinical cases of injury to or of tumors in the frontal lobes are worthy of note. These have been made by Welt,[1] by Phelps,[2] by Müller,[3] and by Schuster.[4] Welt has collected 59 cases of lesion of the frontal lobes in man, and of these only 21 showed mental changes.[5] Two-thirds of the cases reported showed no change in intellectual capacity or in character. An examination of Welt's cases shows, however, that many of them were reported sixty or more years ago, and at a time when physicians and clergy were antagonistic to facts in favor of localization. In some of the records details are lacking regarding the mental life of the patients and these are naturally—but possibly erroneously—considered as having shown no mental change. The celebrated crowbar case (1850) and the case described by Nobele (1835) are among the ones which in opposition to the accepted belief of the time show mental deterioration or change following injury to the frontal lobes.

The collection made by Müller is of more recently reported cases, but the author concludes from the examination of the material that tumors in the frontal region are not always productive of disturbance of the higher mental faculties, although they are frequently accompanied by some mental change. Three cases cited by Müller are worthy of special mention. These are reported by Dévic and Courmont, by Durante and by Rossolimo. The patient described by Dévic and Courmont was a woman, 46 years old, who had a glioma the size of a walnut in the right frontal lobe. She had become mentally weak, stuporous, depressed and suicidal, with motor unrest. An operation was decided upon and carried out and the glioma removed. Following the operation there was a return to the normal condition in a short time. A similar case of operation on the left frontal is described by Durante. The patient was a woman, aged 35, who for a year had shown a decided change in character with an increasing memory defect. The removal of a tumor from the left frontal region was followed by a complete mental recovery after about three months. A man, aged 38, also showed improvement after operation for a cyst and gliosarcoma in the right frontal lobe. Change in character, memory weakness, insane impulses and depression characterized the patient before the operation, in which the cyst was evacuated. After the operation there was an improvement in memory and more ease in thinking. This case was reported by Rossolimo.

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[1] L. Welt, Ueber Charakterveränderungen des Menschen infolge von Läsionen des Stirnhirns, *Deutsches Archiv. f. klin. medicin*, **42**: 339–390, 1888.

[2] C. Phelps, (A) Differential Diagnosis of Traumatic Intracranial Lesions, *N. Y. Med. Jour.*, **60**: 557–582, 710–716, 741–745, 779–785, 807–815, 1894; **61**: 8–14, 37–43, 1895.

(B) *Traumatic Injuries of the Brain*, Second edition, 1900, pp. 602.

(C) Cases Illustrative of the Localization of the Mental Faculties in the Left Prefrontal Lobe, *Amer. Jour. Med. Sci.*, **123**: 563–594, 751–771, 1902.

(D) The Function of the Left Prefrontal Lobe, *Ibid.*, **131**: 457–480, 1906.

[3] E. Müller, Kritische Beiträge zur Frage nach den Beziehungen des Stirnhirns zu Psyche, *Allg. Zeitsch. f. Psychiatrie*, **59**: 830–875, 1902.

[4] C. Schuster: *Psychische Störungen bei Hirntumoren*, 1902, pp. 368. On pp. 1–78 are given abstracts of 147 cases of tumors and other growths involving the frontal lobes.

[5] Schäfer has reported that only 12 were mentally changed (*Textbook of Physiol.*, Vol. II., p. 773). The difference between the counts made by Schäfer and me may be due to the fact that I counted every case that showed any changes in character, emotional tone, memory or attention.

Schuster has collected and abstracted over seven hundred cases of brain tumors, and he reports some observed by himself or in Mendel's clinic.[1] Of these, 147 are growths in the frontal lobes, 46 cases involving only the right frontal, 61 cases involving the left frontal and 34 cases involving both frontals. In 16 cases the location of the tumor is not given. Since we cannot depend upon the accuracy of the observations in the earlier reported cases, I have arbitrarily chosen to consider the results of only those which were published in 1890 and subsequently. This reduces the number of available frontal cases to 49, of which 16 were growths involving the right frontal lobe alone, 18 involving the left frontal alone, and 15 involving both frontals. An analysis of these 49 cases is found in the accompanying table.

TABLE I.—ANALYSIS OF 49 OF SCHUSTER'S CASES OF FRONTAL LOBE TUMORS, DESCRIBED 1890–1902

	Total cases.	Cases with paresis, ataxia, speech defects, epileptic seizures, etc.	Cases showing poor memory, inattention, mental slowing or deterioration.	Cases showing only depression, excitement, hysteria, etc.
Right frontal	16	10	8	6
Left frontal	18	14	14	4
Both frontals	15	11	11	4

Grouping the 49 cases under very general mental symptomatic headings we find that 20 of the patients had poor memory; 15 were inattentive or mentally slow; 11 showed mental deterioration, the character of which is not further described; 4 were irritable; 13 were depressed; 5 maniacal; and 19 had insane ideas or showed Witzelsucht or Moria[2]. One of these cases, that of Vorster, with a tumor in the right frontal region, gave a typical picture of senile dementia. When one knows that the patient was 70 years old it is evident that such a condition may have been due to the changes incident to old age rather than to any cerebral growth. A similar criticism is to be made against the use of a similar case by Mills and Weisenburg, which will be discussed below. Tumors in other portions of the central nervous system give rise to mental disturbances. In many of these cases the mental status is an exact counterpart of that associated with frontal lobe disturbance. The number of frontal lobe cases abstracted by Schuster that showed paralyses, ataxias, speech defects, epileptic seizures, etc., indicate the extension of the growth or its effect (pressure) to other parts of the cerebrum. It is not certain, therefore, that the mental changes are the result of the frontal destruction alone. On the other hand, in not all the cases of frontal lobe injury or tumor were mental changes apparent. Mental disturbance is, however, rather more likely to result from frontal lobe injuries or tumors than from other parts of the cerebrum. In this connection it may be mentioned that Gianelli cites a large number of cases of destructions of parts of the cerebrum, and of those of the frontal lobes only 79 per cent. was accompanied by changes in the mental condition.[1]

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[1] The total number of cases is 775. The volume is an excellent book of reference. The cases are arranged both according to types of symptoms and according to location of the growth.

[2] *I. e.*, change in character or tendency to make foolish puns and jokes.

The most noteworthy and most important collection of cases is that made by Dr. C. Phelps.[2] This author has recorded the clinical histories, accounts and results of operations, and autopsy findings (when necropsies were performed) in 62 frontal lobe cases observed by himself. The description of the cases is a very valuable contribution to the study of the functions of this association area, but from a psychological standpoint there is a lack of definiteness in the description of the mental conditions of the patients whose cases Dr. Phelps cites.

"Loss of consciousness, the event of stupor or the access of delirium have been found to be dependent on the nature of the lesion, apparently uninfluenced by its situation," is a general justifiable deduction made by him from all his cases.[3] From the results of his frontal-lobe cases the following conclusions are drawn:[4] Mental decadence always attends conjoint lesions of both prefrontal regions. Mental decadence always attends lesion of the left prefrontal region alone. Mental decadence never attends lesion of the right prefrontal region alone.

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[1] Quoted from Schuster, *Op. cit.*

[2] *Op. cit.*

[3] *Traumatic Injuries of the Brain*, p. 127.

[4] *Amer. Jour. Med. Sci.*, **131**: 457, 1906.

The cases of frontal laceration cited in his book and the thirty-four cases in his articles do not, I think, admit such broad inferences. Of the eleven cases of laceration of the left frontal lobe only Cases 6 and 9 were undoubtedly conscious and without stupor or delirium, but with a mental change. Ten cases of laceration of both frontals (pp. 130–131) include four patients in whom the mental condition was 'normal' on days following the injury, and Case CCC (p. 580) is probably an example of mental impairment with lesion of the right frontal lobe.

Of the eighteen cases given in his earlier article[1] it appears from the grouping that the author considers 9 of these to be lesions of the left frontal, 5 of both frontals, and 4 of the right frontal. Cases II and VIII, and possibly XVII, should be more properly considered as illustrative of bilateral lesions. A rigidly exclusive policy would throw out Cases II (that of a child only 7 years old) and X (man, aged 76, with marked cerebral arterio-sclerosis and showing signs only, so far as the clinical account goes, of arterio-sclerotic dementia), on account of the ages of the patients, and Cases V, XI, and XV because the patients lived only a few days following accidents. In his recent article 16 cases are given, of which three are lesions of the left frontal alone, 3 of the right frontal alone, 5 of both frontals, and 5 are not classified. Following are brief descriptions of 28 cases in the two articles, excluding those mentioned above, *viz.*, II., V., VIII., X., XI., XII., and XV.[2]

I., left frontal, destroyed by tumor. M., age 32. Motor disturbance, aphasic disorders. Apathy; incoherence; loss of comprehension; mental aberration.

III., left frontal softening and cyst. M., adult. Transient motor aphasia. Apathy; loss of memory; deficiency of power of attention; slowness of comprehension; change of character. Operation, death on fourth (?) day.

IV., left frontal laceration. M., adult. At first, coma; then stupidity; incoherence, although he answered coherently on the third and sixth days. Death on tenth day.

VI., left frontal and slight temporal laceration. M., adult. Apathy; stupor; delusions; incoherence; deficient comprehension; refusal to answer questions. Death on twelfth day.

VII., left frontal atrophy and oedema. M., adult. Apathy; stupor; delusions (although it is said he was rational on the 18th day, "but still had delusions"); delirium. Death on 25th day.

1, left frontal atrophy. M., 35. History of blow on head ten years before second accident. Apathy; no answers to questions; conscious; delirious from sixth day. Death on eighth day.

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[1] *Am. Jour. Med. Sci.*, **123**: 1902.

[2] In the account of cases Roman numerals will be used for the cases given in Dr. Phelps' 1902 article, and Arabic numerals and letters for those in his 1906 article.

2, third left frontal softening. M., 53. Motor aphasia; motor disturbances; comprehended up to morning of death. Death on fifth day.

3, left frontal covered by blood clot. M., 35. Drowsiness; stupor; apathy; could be roused to answer questions; 17th day, comprehension less delayed. Death on 18th day. High temperature from fourth day until death, with exception of 17th day.

XVI., right frontal abscess. Unconscious, from horse kick, 5+ hours. Otherwise mental condition normal until fourth day, when fever began, accompanied by delusions and stupor. Death on sixth day.

XVIII., right frontal disintegration, removal by operation, at age of 6. Left hemiplegia for seven months. "Mental condition absolutely normal." Epilepsy, eight years later; then irritability and excitability. Patient living; age, 32.

7, right frontal destruction. M., 36. Drowsiness, restlessness, nervousness at various times, although temperature nearly normal most of the time. Discharged 54th day, without indication of mental impairment.

8, right frontal disturbance. M., 40. Primary stupor with left arm paralysis and hemianesthesia. Operation. Recovery. No mental disturbance. Discharged on 21st day.

9, right frontal and parietal sarcoma. M., 27. Epileptic convulsions, hemiplegia, anesthesia. No mental disorder. Operation, removal of tumor. Free from mental disturbance a year later.

10, right frontal destruction. M., adult. Shooting accident followed by unconsciousness for four days. Otherwise "intellect was clear and his memory unimpaired." Operation, abscess, second operation. Death about six months after injury. Always perfectly intelligent.

11, right frontal abscess (?). Boy, aged 10. Operation. Epilepsy; mental condition normal; good memory and power of concentration and of comprehension.

VIII., left frontal laceration, hemorrhage over right temporal, oedema of both hemispheres. Incoherence; loss of memory; apathy; delusions. Death on 33d day.

XIII., left and right frontal abscess. Bullet wound. Patient conscious but apathetic. Unconsciousness on 24th day. Death on 31st day.

XIV., laceration of both frontals, general cerebral contusion. Left hemiplegia. "Deficient power of attention and apprehension. Subsequent variable mental condition; sometimes normal, sometimes delirious, usually apathetic, with mild delusions." Death on 26th day.

XVII., bullet wound of right frontal and left occipital, serous effusion over left hemisphere. Conscious, coherent, intelligent until third day, when it was difficult to arouse patient. Death on fourth day.

4, atrophy of both frontal lobes, abscess in cerebellum, pus formation involving left temporal and occipital lobes. Delirious, noisy and restless, attention could not be fixed. Jargon speech. Death on 31st day.

5, extensive softenings of both frontals, and of other parts of cerebrum. M., 40. Delirious, incoherent, aphasic. Death on ninth day.

6, softening of both frontals, oedema of whole brain. No record of mental condition for six months following fall. Only five days in hospital until death. Apathy, stupor.

IX., laceration of left frontal and temporal lobes. M., 35. Operation for effects of blow. Delirium, lack of comprehension, aphasia, mental enfeeblement. Under observation three months. Did not die.

It is unfortunate that all of the individuals with lesions in the left frontal alone, or in both frontals, whose cases are given in Phelps' recent article, died soon after the accidents. We can see, however, that not all individuals had their mental faculties located in the left frontal lobe. The patient in Case 2 with a left frontal lesion comprehended up to the morning of his death. The patient in Case 3, although there was a certain amount of stupor and fever coincident with the left frontal injury, could be roused sufficiently to answer questions, and when the fever had only partially subsided the "comprehension was less delayed." In Case B, a fall on the right side, the patient showed a mental defect for at least two weeks. In Case C, patient was discharged on the twenty-second day with delusion persisting after injury to the right side of the head. In Case D, a fracture on the left side, patient was entirely rational at the end of the fourth week. I am well aware that the cerebral lesions in the last three cases were not determined, but we are as certain that the brain injury in Cases B and C was on the right side as that it was on the left in Case D.

Of the 23 patients whose mental and cerebral conditions are summarized above, about half died within a short time, with definite indications of extensive brain injury. Stupor, delirium, and loss of consciousness depend more upon the extensity of the disturbance than upon its location, and if the clinical histories of the above cases are examined carefully, many of the cases should be excluded which are used to support the 'left-frontal-lobe-intellectual-faculty' supposition. That most of Dr. Phelps' left frontal cases died, notably III., IV., VI., 1, 2, and 3, shows that the brain injury was more severe physiologically than the gross anatomical examinations indicate, or that in these individuals the resistive or recuperative powers were not so great as in others. The greater severity of the injury or the lowered resistive powers would account in large measure for the mental disorders. In Case XVI., mental symptoms intervened when fever began, although the brain injury was in the right frontal region. Case 7 was restless, nervous, and drowsy from a right frontal destruction although there was little fever. In the cases of bilateral lesions it is not surprising that mental disorders were noted, but that the disorders were not greater. All the cases with pus—with the attending probability of toxic effects—with cerebral oedema, etc., are not clear cut cases of loss of function of special parts of the brain, and these should be excluded. In fact, comparatively few of the clinical cases which are cited by Phelps, by Schuster, by Welt, or by Müller as examples of frontal lobe injury, destruction, or growth can be rigidly classified as 'frontal.' In such a matter it would be better to exclude doubtful cases rather than to burden the reader with others which indicate only effects from diffuse cerebral injuries. Dr. Phelps' articles and the cases cited by him are otherwise excellent and more than any other they bring conviction that the frontal lobes are most intimately concerned in mental processes.

The patient whose case was recently reported by Mills and Weisenburg[1] had mental and physical symptoms similar to one cited by Vorster which is criticized above. The patient was a man, aged 71, whose "symptoms appeared at the time to correspond to those frequently seen in cases of cerebral arterio-sclerosis." Almost two years before his death he lost his grasp as a physician, and was later noticed to be rather careless about the house, and about his personal appearance. About six months before his death the patient seemed to develop rather suddenly a memory defect, and there ensued a gradual loss of judgment. From the account of the case, excluding the necropsy findings, one would naturally conclude that the patient had what is usually called 'senile dementia.' The autopsy disclosed a prefrontal tumor on the left side, situated in the anterior third of the first frontal, the anterior quarter of the second, and less than a quarter of the third frontal convolution. The arteries throughout the brain were also found to be markedly sclerotic. This latter condition is sufficient to account for all the symptoms in this case without the intervention of the brain tumor, and it is doubtful if the tumor added anything to the symptom-complex which is found in cases of senile dementia or in the dementia of cerebral arterio-sclerosis. The authors do not discuss the possibility of the arterio-sclerosis as a cause of the mental change, nor do they indicate in what way the mental picture in this case differs from that in senile dementia without brain tumor. In fact, in support of their hypothesis the clinical history is very meagre.

In looking over the cases which are recorded in the literature one is struck by the lack of psychological terminology, and accurate experiment. The case cited immediately above is an example of this although the authors try to indicate that this defect is to be found rather in the writings of others. They tell us, "one of the greatest difficulties of proving the localization of the highest intellectual processes has arisen from the fact that physicians, even those trained in neurology and psychiatry, frequently fail to note the mental symptoms carefully or describe them in such an uncertain manner as to make the records of little value."

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[1] C. K. Mills and T. H. Weisenburg, The Localization of the Higher Psychic Functions, *Jour. of the Amer. Med. Assn.*, 46: 337–341, 1906.

From a psychological standpoint, what is lacking in all the accounts is a careful analysis of the mental condition. Apathetic, dull, stolid, irritable, restless, nervous, deficient memory, slow comprehension, are general terms for conditions which, for scientific purposes and in the present state of psychology, the observer could and should try to describe more carefully. Any one of these terms may be descriptive of states of deficient or wandering attention, some are indicative of a mild degree of delirium. It is of prime importance that every case should be examined from a psychological standpoint, if psychological inferences are to be drawn.

In an earlier article[1] Mills argues for the frontal seat of intellectual states and commends the work of Spitzka and the latter's deductions from a study of the brain of Major Powell. It appears, however, that Spitzka's observations tend to prove the predominance of Flechsig's posterior association area in intellectual men.

On the histological side Campbell and Bolton have attempted to deduce function from differences in structure and from changes which occur in mental diseases. Campbell's division of the frontal lobe on histological grounds has already been mentioned. He thinks the associational part of the frontal lobe comprises about two-thirds of its anterior part.[2] This he divides into two areas, the frontal and prefrontal. The frontal area is highly developed, he says, not only in cell arrangement but also in the supply of fibers. On the other hand, the prefrontal is rather poorly developed both in fibers and cells and he says "it cannot share the functional importance of the better developed frontal cortex placed further back; in short, although it may have a future in front of it, at present its evolution both structural and functional is incomplete." From a consideration of the clinical and physiological work Campbell is inclined to consider the frontal lobe of great importance in the performance of mental operations. The discrepancies between the results of the physiological work of Horsley and Schäfer and that of Bianchi, he thinks are due to differences in the amount of the frontal lobes which were extirpated. "Horsley and Schäfer obtained negative results because the mutilation in being confined to the anterior third or quarter of the frontal lobes was too small in extent, and having regard to the weak development of the prefrontal cortex" he thinks no obvious mental change could have been noticed.

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[1] The Physiological Areas and Centres of the Cerebral Cortex of Man, with new diagrammatic schemes, *Univ. of Penn. Med. Bull.*, **17**: 90–98, 1904.

[2] A. W. Campbell, *Histological Studies on the Localization of Cerebral Functions*, 1905, pp. xix + 360. 29 plates.

Bolton[1] working with different material, mostly pathological, and using a rougher method, *viz.*, the measurement of the depth of the cortex in cases of normal and subnormal mental development, concludes that "the anterior center of association of Flechsig is the region concerned with attention and the general orderly coordination of psychic processes." "The great anterior center of association lying in the prefrontal region (= frontal and prefrontal of Campbell) is underdeveloped on the one hand in all grades of primary mental deficiency and on the other undergoes primary atrophy pari passu with the development of dementia; it is therefore the region of the cerebrum which is concerned with the performance of the highest coordinating and associational processes of mind." In the dementia of general paralysis he shows "that the centers of association are more severely affected than those of projection." In all cases of dementia a similar result was found. "In cerebral dissolution the order of retrogression is the reverse of the order of evolution."

On the physiological side many experiments have been made and investigators have found little mental change after extirpation of the frontal regions. Loeb,[2] following Goltz, denies the possibility of the localization of mental states in the cerebrum in special parts. However, he says that "if we remove the anterior parts of both hemispheres, a dog remains no longer normal but becomes idiotic." "While dogs after the loss of the anterior halves of the cerebral hemispheres often become irritable and ugly, dogs which lose the occipital halves of both hemispheres invariably become good-natured and harmless" (p. 264). Again, "I have repeatedly removed both frontal lobes in dogs. It was impossible to notice the slightest difference in the mental function of the dog. There is perhaps no operation which is so harmless for a dog as the removal of the frontal lobes."

Schäfer and Horsley[3] found no mental impairment following destruction of the frontals in monkeys, "an operation which may indeed be effected without producing any very obvious symptoms."

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[1] J. S. Bolton, The Functions of the Frontal Lobes, *Brain*, **26**: 215–241, 1903. Amentia and Dementia: A Clinico-Pathological Study, *Jour. Ment. Sci.*, **51**: 270–340, 507–539, 659–676, 1905; **52**: 1–28, 221–277, 427–490, 1906.

[2] J. Loeb, *Comparative Physiology of the Brain and Comparative Psychology*, 1900.

[3] *Phil. Trans. Roy. Soc.*, 1888. See also Schäfer, *Physiology*, II., p. 772.

They report a more extensive mental change accompanying lesions of the temporal lobes and describe this condition as one of 'semi-idiocy.'

Bianchi has, however, reported[1] changes coincident with destruction of the frontal lobes in both monkeys and dogs. He criticizes the work of Horsley and Schäfer, making the same point that is made by Campbell, *viz.*, that they operated upon only the anterior third or fourth of the frontals. His own experiments on twelve monkeys and six dogs, ten of which monkeys were kept for long periods, gave the following results from unilateral extirpation of the frontals. During the first and second week there were rotary movements toward the mutilated side, but no concomitant oculo-motor disturbance. These motor effects remained for only one or two weeks. The tactile sensibility remained normal and in only one or two cases did he find what appeared to be any anesthesia. In all animals there was a visual disturbance of the nature of an hemianopia. "No perceptible differences were noted in the behavior or psychical manifestations of animals mutilated on one side only."

In his article Bianchi gives the details of the condition of one dog and three monkeys upon which he operated bilaterally. The dog had the frontals removed one at a time, the operations being a month apart. The sensory and motor functions were determined before the operation and in all of Bianchi's work he stimulated the cortex and determined the anterior limit of the motor area before he attempted to extirpate these regions. After the loss of the frontals this dog recognized its kennel but seemed to have no 'sense.' He ate everything, got tangled up, but avoided obstacles. It appears, although it is not directly stated, that this dog had previously been operated on in the occipital region for he is reported to have been 'amblyopic through occipital mutilation.'

A chacma baboon that had learned to walk on all fours or on the legs only at command and to render a military salute, had the left frontal excised, after which it was found that the animal did not give the military salute. It could not properly use its right hand and the external segment of the field of vision of the right eye seemed to be involved. The animal, however, was susceptible to new adaptations. Two months and a half later the other frontal was extirpated. The left eye became almost completely blind. A week after the operation "she was afraid of the other cynocephalus whom she previously used to hug with evident pleasure." She lost her previous interests, as, for example, in the puppy whom she used to hug and fondle. Two months after the removal of the second frontal she could be tempted to start the 'salute' although she was indifferent, and the author remarks that under novel conditions she was not capable of new adaptations. We are not told whether or not the attempt at the 'salute' noted above followed numerous commands on preceding days or if this was the first time the author attempted to determine the presence or retention of the association.

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[1] L. Bianchi, The Functions of the Frontal Lobes, *Brain*, 18: 497–522, 1894. On the teachings of Flechsig with regard to the Perceptive and the Associative Zones (abstracted in the *Review of Neurology and Psychiatry*, 3: 189).

A similar observation has been recorded by Hitzig of one of his dogs. The dog had been accustomed to find its food on a table and to take it therefrom. When both frontals were excised the animal lost the association. This line of work does not seem to have been followed up either by Hitzig or by Bianchi.

Another female chacma previous to operation was docile, inquisitive and lively. At the first operation the right frontal was excised and in a week, to all intents and purposes, the animal was in a normal mental condition, but subject to fear and with a slight left external hemianopsia, which disappeared very shortly. About six months later the left frontal was excised. About forty-eight hours after the second operation it was noted that the animal remained "in its cage, head bent, eyes half open, sleepy but sitting. No deviation of the trunk or paralysis." Later it was found to have aimless walking, loss of expression, and stupid attitudes. It took bits of plaster in the form of sugar cubes and ate them as if sugar. She could not "resist the idea of sugar which the appearance of the plaster evoked." This condition remained stationary for months.

The third baboon whose history is reported in full was an agile, inquisitive, cunning animal, attached to her keepers. Both frontals were removed at the same time. Following the operation there seemed to be some slight hyperesthesia on the left side and the animal walked badly with her head and body bent and swaying. The left leg dragged and the right arm was little used. There seemed to be no curiosity or interest in what went on. She no longer hunted for fleas with her customary rapidity. A cherry with quinine was eaten almost as readily as one without. She also ate plaster as if sugar, and wax which was colored and in the form of a cherry. Two months after the operation her behavior seemed to have been altered from what it was before the operation; her physiognomy was stupid and less mobile, she showed terror, but never reacted aggressively. There was a state of unrest. She seemed to have no affection. She was unsociable. She could not play and could not adapt herself to new things or learn or recover what she forgot. A month later she could differentiate between sugar and plaster, although the author says "the whiteness of the fragments (of plaster) and their resemblance to those of a sugar plum prevailed over her sense of taste."

The conclusions which Bianchi draws from all his experiments are that "the frontal lobes are the seat of coordination and fusion of the incoming and outgoing products of the several sensory and motor areas of the cortex. Removal of the frontal lobes does not so much interfere with the perceptions taken singly as it does disaggregate the personality and incapacitate for serializing and synthesizing groups of representations" (p. 552). In the operated monkeys "their affective nature, friendliness and sociability is impaired, their avidity becomes reckless and insatiable. From cleanly they become dirty. Their sexual functions are perturbed, the females menstruate irregularly, the males become, if not incompetent, at least incapable. All these symptoms depend not upon motor deficiencies of the head, neck and trunk muscles, but upon a dissolution of the psychical personality."

Schäfer criticizes the results and conclusions of Bianchi and tries to explain them and his own negative findings from frontal destruction as follows: In his own work the frontals were not removed. In Bianchi's work the frontals were removed from the cranial cavity. His own method, he says, interferes less with the vascular supply and less shock is present from the operation. When portions of the brain are taken out there is mechanical and physical disturbance of the whole hemisphere "which may lead to erroneous conclusions."

The criticism which must be made against all the physiological work which has just been mentioned is one similar to that made above in connection with the record of clinical cases. The observations which physiologists have made are as 'casual' as those made by clinicians. The term 'semi-idiocy' used by Schäfer does not mean anything from a psychological standpoint and, particularly since idiocy in children is difficult to diagnose from simple observation, it is impossible to determine such a condition in dogs or monkeys.

III. EXPERIMENTAL METHODS

Because the observations and the terms used by physiologists to describe the effect or effects following the removal of the frontals were so inexact I devised, about six years ago, a method by which we could determine the presence or absence of certain definite associative processes in animals before and after removal of any part of the cerebrum. This method is an extension of the 'salute' experiment made by Bianchi and of a similar experiment by Hitzig.

A. Operative Procedure.—It may be well to give somewhat in detail the procedure which I used in the operations. The animal was placed on the table, anesthetized lightly, and bound to an animal board so that the preliminary part of the operation could be done without excessive struggles on the part of the animal. On the portion of the head where the incision was to be made, the hair was first cut with scissors and on the scalp there was placed a depilatory solution,[1] which removed all of the hair much more easily and more completely than could be done by shaving. Moreover, the scalp was not broken and there was less chance of infection. The head was then washed with bichloride solution 1–1000 and a cloth or piece of cotton wet in the solution was placed on the scalp until I was ready to make an incision.

For an anesthetic I generally used the A.C.E. mixture, occasionally ether or a mixture of ether and chloroform. In cats, in addition there was sometimes given by mouth a quantity of chloral hydrate, chloretone or urethane sufficient to keep the animal quiet after the operation for a number of hours.

The incision of the scalp was a semicircular one depending, of course, upon the region where the bone was to be trephined. In the frontal region this extended almost from ear to ear, coming close in front to the supraorbital eminence. With this cut there was more or less bleeding from the scalp, which was readily controlled by means of large hemostats, which are employed in uterine work. The openings of the skull were made with a half-inch hand trephine and these openings were enlarged by means of bone forceps when necessary. The button which was removed by the trephine was kept in warm normal saline solution or in bichloride 1–2000. In trephining there was always considerable hemorrhage from the diploe, which was controlled by means of bone wax (two parts wax, one part oil). With the bone removed the dura was visible. This was cut, avoiding large blood vessels, exposing the whole area covered by the trephined button. The site for the incision into the brain substance was determined sometimes by means of electrical stimulation and the lack of response to such stimulation. A fine cataract knife was then inserted into the brain substance as close to the longitudinal fissure as could be done. It was pushed down to the orbit, then drawn outward toward the side of the head, severing as completely as possible all connection of the region with the rest of the cerebrum. The piece of tissue which was cut away was left *in situ,* thus obviating the criticism made against the work of Bianchi by Schäfer. Bleeding from the brain substance was controlled by compresses and by the application of hot normal saline solution. Occasionally, bulging of the brain substance through the trephine openings was found and this was always well controlled by means of compresses. So soon as the bleeding had ceased the wax was taken from the diploe and the wound was closed, first by drawing together the divided dura, then the insertion of the trephine button, and finally the sewing of the scalp. The scalp was sewn with catgut or kangaroo tendon. The site of the operation was thoroughly washed with bichloride. A piece of gauze was then placed over the scalp incision, with an extra thickness over the 'button' areas, collodion was poured on this, and the whole firmly adhered to the scalp.

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[1] The solution which I have employed is the proprietary article called "Sulphur Starch." This material is being extensively used now to take the hair away from parts which are not readily accessible to shaving and in itself it is antiseptic. Such depilatory preparations would be of much value in other psychological and physiological experiments.

The bandage was then placed over the head, leaving out the ears, but going under the jaw. This bandage was usually sewed so that the animal could not tear off the successive layers. This prevented both cats and monkeys from interfering with the wound and was a most satisfactory part of the procedure. This bandage was taken off in about four or five days, sooner if the animal showed signs of oedema or sepsis, and by that time the wound was almost completely healed. The stitches which remained were pulled out and the animal usually had an uneventful recovery so far as the operation is concerned. In only a few cases was it necessary to put a new bandage on the head of the animal and the thorough antiseptic precautions prevented in all but one or two of my earlier cases the formation of pus and any general infection.

B. The Formation of Animal Habits.—The object of my experiments was to determine whether or not animals with frontal lobe destruction retained simple associations or could form associations. The method employed for the production of simple associations is that used by Lloyd Morgan and by Thorndike and others.[1] Briefly described, the method is as follows: The animal is placed in a certain environment, usually unpleasant or indifferent to the animal. By simple motor adjustment the cat or the dog or the monkey gets a subsequent pleasure. At first the motor response is neither accurate nor speedy. At the beginning of any series of experiments the animal makes random movements according to its nature, scratching, pulling, biting, and feeling everywhere. By chance it hits upon the proper movement and after the experiment has been repeated a number of times the unnecessary movements are eliminated. Only those movements are retained which tend to make the pleasure come sooner, and consequently the time in which the act is performed gradually decreases. Usually after ten trials with monkeys or twenty to thirty trials with cats or dogs, the motor response is received immediately after the animal is placed in the desired environment.

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[1] See the author's early article in the *Amer. Jour. of Physiol.*, 8: 1902.

The activity of the animal is well described by Thorndike:[1] "When put into the box the cat would show evident signs of discomfort and impulse to escape from confinement. It tries to squeeze through any opening, it claws and bites at the bars or wires, it thrusts its paws through any opening, and claws at everything it reaches. It continues its efforts when it strikes anything loose or shaky. It may claw at things within the box. It does not pay much attention to the food outside but seems simply to strive instinctively to escape from confinement. The vigor with which it struggles is extraordinary. For eight or ten minutes it will claw and bite and squeeze incessantly. . . The cat that is clawing all over the box in her impulsive struggle will probably claw the string or loop or button so as to open the door. And gradually all the other non-successful impulses will be stamped out and the particular impulse leading to the successful act will be stamped in by the resulting pleasure until after many trials the cat will, when put in the box, immediately claw the button or loop in a definite way."

In my earlier research only cats were used, in the later experiments only monkeys.

The environments for the cats were similar to those used by Thorndike—animal boxes from which the animal could escape by pulling a string, pressing a button, etc. Escape from the box always meant 'food.' The boxes were about 12 inches high, 15 inches wide, and 20 inches long. The bottom, back and sides of the boxes were solid boards, the front and top were made by placing three-quarter inch slats about an inch apart except at the door. The door was about six inches wide and eight inches high, hinged at the bottom and so arranged that it would fall outward when the proper mechanism was pressed. An illustration of one of these boxes is given in the accompanying figure. In addition to the box here illustrated two other boxes were used. In one the cord passed upward and over the top of the box to the back where it was fastened. In this box, at the place where the cord passed over the top, a wire netting was arranged about three-quarters of an inch above the cord. The door would fly open if the cord was pulled by the paw or teeth or if the head or back were strongly brushed against it. On the third box the cord passed upward, then downward and outward to a point about three inches to one side of the door and about two inches in front of the slats. The animal would escape from this box by strongly pulling or pressing against the cord. In the remainder of this article these boxes will be called respectively *button, string above* and *string front.*

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[1] Thorndike: *Animal Intelligence*, p. 13.

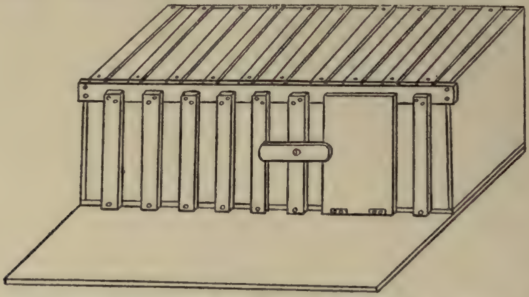

Fig. I.—Box from which animal could escape by pressing button up or down.

Two arrangements were used with the monkeys: one, which I shall call the food box experiment, consisted in a large cage with a smaller *food box* attached to it outside and at one corner. The cage was made of wire netting about 18 inches cube and the food box was attached at the back in the upper right-hand corner. The food box was 7 inches cube. The front of the food box was part of the back of the cage and its door opened directly into the cage. The door was fastened by an old-fashioned turn button similar to the one in the cat box illustrated above. The button had to be turned through an angle of 90 degrees before the door of the box could be opened. A greater or less turn would keep the door of the box closed and at times the animal would turn it around too much so that a number of extra efforts would have to be directed against the button to keep it in the exact location for the opening of the door. The button of the food box was placed sufficiently high so that the animal had to stand and reach for it. A hungry animal was placed in the small cage, food was put in the box and the animal attempted, particularly after its first few trials, to get at the food.

The second association which was taught the monkeys was what may be called the *hurdle.* This gave a situation a little more complicated. The animal was placed on a box 10 inches high from which it jumped or walked to a bar 15 inches high, thence to a bar 10 inches high and through a hole in a box which was six inches deep, the hole itself being six inches in diameter, then up and down two short ladders placed together and finally it lifted the lid of the middle one of three boxes in which it found some food.

Neither my cats nor monkeys were kept in such an extreme condition of hunger as Thorndike's cats and dogs, and they were probably slower in getting associations formed. The main object of the work, however, being to get the associations formed rather than to determine the time for this formation, this is of no consequence. With the monkeys it was found advisable to accustom the animal to the cage for some days before any experiments were made with it and at times during these days the animal was put in the cage and was fed slowly by the food which it found in the food box, small pieces being placed there from time to time during periods of about an hour.

When an animal had learned the association of opening the door of *button, string front, string above, hurdle* or *food box,* it was usually put aside for a week or ten days with no practice, and then its memory was tested. In most cases a few extra trials to get the habit well learned were given and then the frontal lobes were cut away from the rest of the cerebrum. In some cases the animal was set aside for longer periods and its memory tested after intervals of two, three, or four months. This was the case particularly with some monkeys and this matter will be mentioned when the experimental results are being considered. About 35 cats were used in the experiments but not all of these survived the operation for a sufficient length of time to make their results of value in this work. Ten of the monkeys learned one or both of the associations and survived the operation for a sufficient length of time to determine the presence or absence of the sensory-motor associations. Eight of the monkeys were of the macacque family and two were ringtails.

The cats were placed in the boxes when hungry, food was placed outside, and each cat was watched until it had opened the door and had obtained the milk or meat or fish. With the monkeys, an animal was placed in the food box cage—and watched until it had opened the door and obtained the food; or, attached to a chain and collar, it was placed on the first part of the hurdle and observed until it had gone over or through the various obstacles to the boxes at the end. In this latter experiment the animal did not at first understand what was wanted, but by means of its chain it was pulled through until it would voluntarily start by itself.[1] The time for the performance of the act in the experiments was recorded, and the speed together with the elimination of random movements indicated when the habit was well formed. In the case of cats the time of escape from the boxes after twenty or thirty experiments averaged about two or three seconds. The 'food box' adjustment could be made by a monkey in about one second after 10 to 20 trials. The time for the 'hurdle' could not be easily determined, because any movement of other animals in their cages or of the experimenter produced a distraction, and the animal usually paused to look about.

The retention of the association under any set of conditions, *e. g.*, after an interval of a month, or after the extirpation of part of the cerebrum, may be learned by placing the animal in the box or other appropriate environment. If the time for the performance of the act of turning the button or pulling the string, etc., remain the same as when the earlier experiments were made, we are warranted in saying that the association is retained and the nervous connections for the performance of the habit have not, in the case of extirpation, been interfered with. If the time be somewhat longer or the motor response not so accurate, we may obtain a fair idea of how well or how ill the habit has persisted. If the association appears to be lost, if the animal does not act in an appropriate manner in its environment, we can conclude that the nervous tracts have been interfered with, either functionally or anatomically. In this latter case, if the time interval between the trials be long, and if the animal has not been operated upon, we conclude that the 'memory' for the particular act is lost; if there has been operative interference, the loss of the habit may be due to an inhibitory action (in the case of man such inhibition may result from fever and its attending delirium or from that little understood state called 'shock'), to the section of the nervous tracts or to destruction of the nervous elements by which the association is produced.

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[1] Thorndike seems to doubt the possibility of doing this for he says that "no animal who fails to perform an act in the course of his own impulsive activity will learn it by being put through it." (*Animal Intelligence*, p. 68.) In this experiment, *viz.*, 'hurdle,' the association is undoubtedly more complex than in the case of 'food box' and too much time would have been used by allowing the animal to get the association formed by its own impulsive activity. The method was adopted and used with success, so that much time was saved. The fact that animals can learn in this manner is of interest from the standpoint of animal psychology, but no discussion of it will be attempted here. In the present work the important factor was the production of the habit or association, and any method was justifiable that would have the habit fixed in the shortest possible time.

IV. RESULTS

Two series of animals were used in the course of the work, namely cats and monkeys. Cats were found very convenient to handle and easy of operation. On the other hand, the monkeys give results which are more nearly in accord with what we should expect from man. The accompanying figures give an idea of the appearance of the brains of these two animals. Fig. II. is an illustration of the cat's brain from the superior and lateral aspects and for convenience I have marked on the diagram that part which is known to be concerned more especially with movement. The crucial sulcus is the posterior limit of the frontal lobes corresponding in a way to the Rolandic fissure in man and in monkeys. The supraorbital fissure divides the frontal region into the post- and prefrontals and in the experiments I endeavored to extirpate always in front of the crucial sulcus and often, as will be found in the later diagrams, the section was made in the immediate neighborhood of the supraorbital fissure. In my hands stimulation of the region between the supraorbital and crucial fissures did not give any constant motor response although occasionally slight muscular movements were noticed.

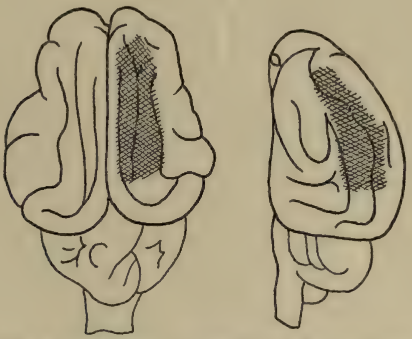

Fig. II.—Diagram of a cat's brain, reduced. Adapted from Wilder and Gage, and from Ferrier, showing the superior and lateral aspects of the cat's brain. The motor area is indicated by cross hatching.

A diagrammatic illustration of the brain of a macacque is given in Fig. III. The motor region in the macacque is situated anterior to the fissure of Rolando and adjoining the precentral sulcus. Anterior to the precentral fissure we may count as the true frontal region comprising the prefrontal and the frontal. In the operations, except where the attempt was made to extirpate other regions, I endeavored to limit the lesions to the portion of the cerebrum anterior to the precentral fissure. The diagrams which accompany the account of the experiments illustrate how well this has been done.

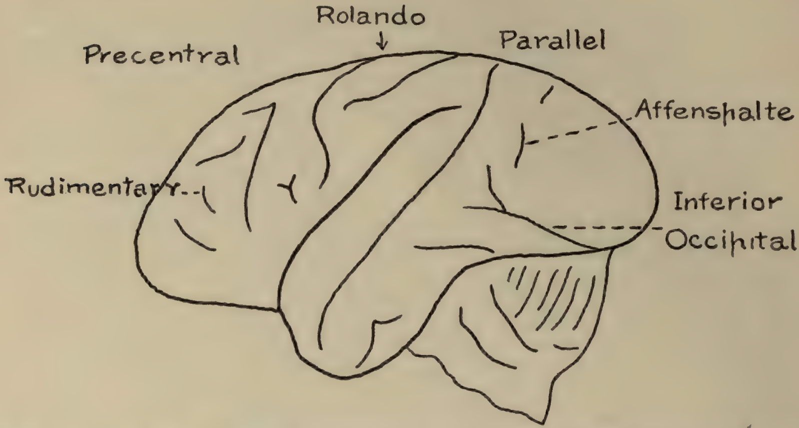

Fig. III.—Diagram of brain of macacque monkey (giving the lateral aspect of the left hemisphere). From Lesem, *Journal of Comparative Neurology*, 1903. Only the principal fissures are here marked.

A. The Loss of Habits after Extirpation of Both Frontal Lobes

In Hitzig's experiment we have seen that the dog could not find its food on the table after the removal of the frontal areas. The result obtained by Bianchi with his chacma who had previously learned the 'salute' is about the same. We may say that in both cases the association of the sensory and motor parts of the habits was lost or at any rate greatly disturbed. Similar results were obtained by me with all the cats upon which I operated bilaterally in the frontal region. Some of the monkeys give the same results and others, as will be seen, gave negative results. The account of these experiments follows.

I. Cat 4. Very active female about 5 months old. This animal learned in a period of a week the habits or associations of *button* and *string above*. At the end of the week's test the cat escaped from either box in from one to two seconds. The cat was operated upon and both frontals excised[1] at the operation. Later in the day the animal seemed in good condition but of course rather sleepy from the effect of the anesthetic. On the following day, however, it seemed dazed and would not eat. However, it followed me about the animal room when called, though not by name, and it is to be noted that this coming to a call is a habit that was not lost. In its cage it appeared restless, moving up and down in front of the wire netting and very slight noises seemed to affect it. Two days after the operation the animal seemed much better. It ate well and nothing unusual was quoted about it; its restlessness had very largely disappeared. At this time it was tested in regard to the retention of the habits which had previously been formed and these were found to have been lost. During the following six days the animal was repeatedly tested in both boxes but there appeared to be no evidence of retentiveness.[1] At this time other observers said the cat appeared to be very much like a normal animal. Soon, however, signs of distemper appeared and the animal was killed to prevent contagion, nine days after the operation. During the progress of the experiments after the operation it was noted that when the cat was put in one of the boxes it would put its nose or its paws between the slats and it would scratch around in the same manner as it did when it began to learn the associations. To all who observed the cat at that time it was evident that no memory of the habits was present. It is interesting to note, however, that six days after the operation the cat succeeded in escaping from the *string-above* box by crawling out of the top. In all the boxes used with cats a top slat was left unfastened as a convenient method of putting the animal into the box. In this case the cat accidentally pushed aside the slat and when it noticed this it immediately crawled out. Before the operation in these experiments this slat was held down by a brick or by the experimenter's foot, so that no 'memory' can be said to have been present of such a means of escape. In fact, the slat was accidentally pushed aside and it was some time before notice was taken of it and escape effected.

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[1] The terms excision, removal, ablation, extirpation and the corresponding verbs are used, because of lack of better ones, to indicate that the frontals or other parts of the cerebrum were separated from the remainder of the brain.

Another observation of interest is in regard to emotional reaction. In the animal room there was a cage of mice. Immediately before the operation each cat was held in front of this cage and its reactions noted. In this cat, as in all others, the same sort of response was obtained after the operation as before it. The heart beat more rapidly, the eyes followed the movements of the running mice, and it repeatedly attempted to jump from my arms upon the cage in order to obtain its prey.

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[1] Two minutes were allowed the animal as a sufficient time in which to open the door. If the cat did not pull the string or push the button in the two minutes, it was taken out and the trial was counted a "failure." This amount of time was sufficient for the cat to open the box if the association was retained.

A diagram of the brain of this animal is given in the accompanying figure. On autopsy the brain was found normal except at the point where the incision into the brain had been made. No hernia of the brain substance was found and the scalp wound was well healed. The part of the brain destroyed by the operation, it is seen, is well within the frontal areas.

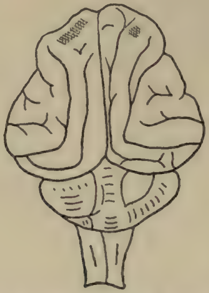

Fig. IV.—Brain of cat 4, from superior aspect, showing points by cross-hatching where the frontals were cut away from the rest of the brain.

This case is typical of all the other experiments in cats, and it is important to keep in mind the following four facts: (*a*) The recently formed habits of opening the box by pressing on the button or pulling at or pushing the string were lost after extirpation of the frontal lobes. (*b*) The impulse (or we may say the inherited habit or tendency) to escape from an enclosed space remained perfectly under the same conditions. (*c*) The habit of coming at call was retained. (*d*) The emotional response was the same after as before the operation.

II. Cat 5. An active female about six months old. This cat also learned to escape from the boxes *string front* and *string above* in 2½ and 6 seconds, respectively, after practice of 8 days.

Both frontals were excised, the cat having been anesthetized with ether and given 0.75 gram chloral hydrate by mouth. For three days after the operation the cat was drowsy and apathetic. When taken from the cage it would walk a few steps and then stop. There was no motor defect and no sensory change so far as I could determine, although it seemed to have no objection to wetting its paws and in this respect differed from a normal cat. Three days after the operation it appeared quite normal, but when put in the boxes to determine its retentiveness it did not pull the *string* in *front* or the *string above*. It clawed about the cage, endeavoring to get out, sat down quietly for a few seconds and began all over again.

In the two minutes which I allowed it for this it did not hit upon either of the strings to make its escape. After this time and until it was killed, ten days later, nothing unusual was noted in its behavior except that it did not retain the habits that had previously been formed. Four days after the operation, in regard to *string front,* I made the following note: "In a general way the cat seems to remember the place where its paw should be put to get at the cord but the paw is placed only between the slats, not through them." By 'remember' I here meant that there were more impulses at or near the appropriate space through which the cat should have put its paw. In *string front* it will be remembered it was necessary for the animal to put its paw about two inches beyond the bars to enable it to properly pull the string.

This animal showed the same sort of emotional response when held before the cage of mice as had cat 4.

The accompanying diagram shows the points of the lesions in this animal. In this case there can be no doubt that only the prefrontal region was extirpated, the lesion or the part extirpated being exclusively at the tip of the frontal lobe.

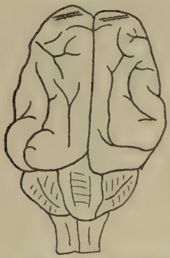

Fig. V.—Diagram of brain of cat 5.

III. Cat 9. Female, about 8 months old. This animal was practiced on the same boxes as the previous cat for a period of two weeks, at which time both habits were fully formed. The times for escape averaged 3 and 5 seconds, respectively, for *string front* and *string above.* Two weeks later its normal retentiveness was tested and found to be good. It escaped from *string front* in an average time of 2½ seconds (5 experiments) and in 6 seconds for *string above* (5 experiments). Although the habit was perfect, the animal was further practiced at intervals of three days until operation, which occurred ten days after these memory tests.

The animal was given three-tenths of a gram of chloretone and during the operation ether was used. Both frontals were cut. The animal had a good recovery after the extirpation and on the following days seemed quite like a normal animal. It had no motor disturbance nor were there any sensory changes noticed. It followed me about the room but when placed in the boxes the appropriate responses were not obtained. It moved around within the boxes, scratched in different places, put its paws between the bars and several times it would paw in the proper place to pull the string. In these cases, however, it did not complete the movement. The impulses to escape were about the same as they were in the first part of the experiments, but perhaps the animal was a trifle less active. Trials to determine its retentiveness were given at various times during two weeks after the operation until it was killed, but it showed no signs of retentiveness of the habits.

The emotional effects before and after the operation were the same as in the preceding cases.

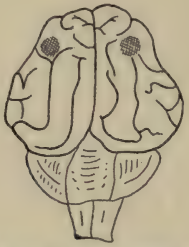

Fig. VI.—Diagram of brain of cat 9. The lesion in this case was further back than in any other frontal operations.

In this animal the autopsy showed that the lesions were much behind the point intended; in fact the knife went through a part which might be distinctly called the motor areas, but it should be remembered that no motor defects were found after the operation. The accompanying figure gives an idea of the lesions in this case.

IV. Cat 11. Female, about 9 months old. This cat was trained for a period of nine days, at the end of which time it developed signs of distemper. During this period it was isolated and not used for experimental purposes. It recovered after about 17 days, when its retentiveness was found to be excellent. It was again given a few more trials at both *button* and *string above,* and its memory tested again after a 39 days' interval, when it was found that the habits were well retained. The cat was given 0.5 gram of chloral hydrate in addition to A.C.E. mixture at the time of operation. Both frontals were cut away. Five hours after the operation the animal seemed quite normal so far as its motor activity was concerned except that it was inclined to remain very quiet, and a short while after the operation it had an 'ether and chloral drunk.' The drowsiness and inactivity were undoubtedly caused by the chloral. The day following the operation it responded to a call and there were some slight inaccuracies of adjustment in walking. These motor disturbances disappeared by the following day and they may have been due to the chloral. This day the animal did not solve the problem of the boxes. The following day and for five days more the cat was placed in the boxes each day, but during this period, although very active in scratching about the boxes and trying to escape, there was no evidence of retention of the habits. After the seventh day the cat slowly relearned the habits but this matter will be more fully considered in a later portion of the article.

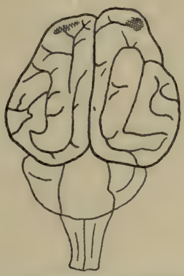

Fig. VII.—Diagram of brain of cat 11.

The lesions in this animal were found to be in the frontal region anterior to the crucial sulcus, that on the right being more on the lateral aspect of the cerebrum. There was no hernia or other disturbance beyond the cut.

V. Monkey 5. Female rhesus (macacus rhesus) about a year old. This animal learned after about 5 days (25 trials) to solve the button of the *food box*. It was then put aside for a period of ten days and its memory tested, which was found to be perfect. The average time for opening the button before the interval was two seconds. Both frontals were then cut, the operation, as in cats, being performed in the manner which Schäfer advocates, *viz.*, the separation of the frontals from the rest of the brain without the removal of these portions. The animal recovered from the anesthetic (A.C.E. mixture) well and in the afternoon ate food, a lump of sugar, and drank water. There was no incoordination in taking the food or in taking the shells off peanuts. It walked well, although it seemed a trifle drunk, but the following day I could not determine any change on the sensory side. The day after the operation the animal was tested in the box but it did not go near the *food box.* For the next two days it still showed no retentiveness of the habit and some time during the third or fourth day the animal died. The cause of this is unknown, but it is probable that pneumonia set in. During the time it lived after the operation, namely three days, it was not so active as it had been, but it was active enough to open the door of the food box if the habit had been retained. Figure VIII. shows the brain of this animal and it is seen that both frontals had been excised anterior and close to the precentral fissure.

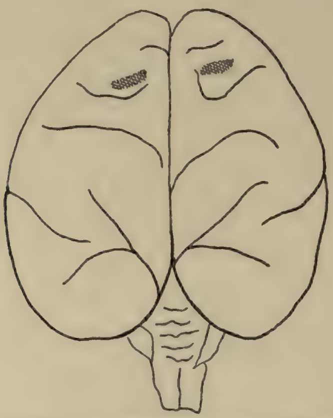

Fig. VIII.—Diagram of brain of rhesus 5.

VI. Monkey 12. Female rhesus about 9 months old. This animal also was practiced in the *food box* experiment, which was learned after 30 trials, so that the animal obtained its food in an average time of one and a half seconds. Two weeks' interval without experiments of this kind were then given and it was found that the animal retained the habit after the fourteen days. The operation on both frontals was performed and the animal seemed quite drowsy and apathetic for the rest of the day. The following morning it was brighter. It seemed to have no defect of movement or of sensations. It conveyed food to its mouth well. This animal was quite active. When put in the cage to test its retentiveness two days after the operation it shook the netting over the door and peered around all over it, but did not pay any special attention to the food box. It was taken out in two minutes, a procedure which I have already said I followed with the cats. It was tried again the following day and its appearance and actions in the cage were that of an animal that was in a new situation. It acted as if it had not been in that cage before. The animal died on the fifth day.

At the autopsy it was found that there were some hernia of the cerebral substance coming through the openings made by the trephine but the lesion was within the frontal region. Death in this case may have been due, but this was not determined, to the increase in intercranial pressure and to oedema of the brain.

Figure IX. gives a diagram of the left side of the cerebrum of monkey 12. The areas which were extirpated comprised, as will be seen, all of the prefrontal and part of the frontal.

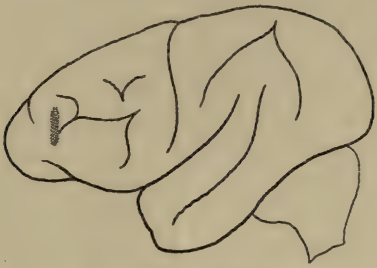

Fig. IX.—Diagram of brain of monkey 12.

These last two cases lived, as noted above, only a short time, and in themselves are probably of little value in drawing conclusions, but must be considered in relation to the results of the next cases in which the animals lived for a sufficient period after the operation to insure the surety of the findings. It should be noted, however, that both animals lived as long after the operation as many individuals do after accidents whose cases are used by clinicians and considered of much value.

VII. Monkey 22. Female rhesus, about 15 months old. This animal was practiced on both ladders and food box for ten days over a period of two weeks, 5 experiments each day. After it had thoroughly learned both *food box* and *hurdles* so that the *food box* could be opened in an average time of about two seconds and the *hurdle* could be gone over and through in about 15 seconds the animal was operated upon and both frontals extirpated. The animal recovered from the effect of the anesthetic quite well so that five hours after the operation it seemed quite lively and ate food and drank water. There were slight ecchymoses about the eyes the following morning. The bandage had been put on tightly and there was a slight oedema of the head. The bandage was taken off, replaced more loosely and the oedema disappeared. The day following the operation the animal was quite normal, a little restless perhaps, but with no evident sensory or motor defect. When tried on the second day over the *hurdles* it had to be pulled along by the chain.

Even then at the end it did not appreciate that one of the boxes was to be opened so as to get its food. This habit at this time did not seem to be retained. On the third day it was tried in the *food box* cage but made no move to turn the button. At intervals during the next ten days the animal was tried on both pieces of apparatus and at no time did it show any signs of retention of the appropriate motor adjustment. The animal was then allowed to rest without any experiments for a period of several days and then I began actively to attempt its re-education in the same manner as I had with cat 11 (Case IV.) and this matter will be discussed in a later portion. The animal died 52 days after the first operation as a result of a second operation on the frontal lobes. A diagram of the brain showing the sites of the lesions is given in Fig. X.

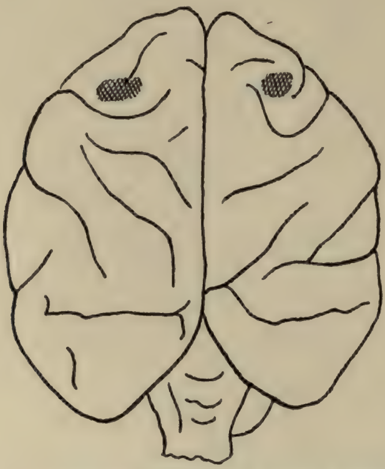

Fig. X.—Diagram of brain of female rhesus 22.

VIII. Monkey 8, male ringtail. The preliminary experiments with this animal, namely in the habit of the *hurdles*, were extended over about a month. Eventually the animal learned to go over and through the ladders and to select the middle box in which the food was placed. At the same time the animal had learned, and in fact had acquired the habit some months previously, of jumping from a shelf to my shoulder when I snapped my fingers.

The operation was performed on both frontals. Two days later the animal climbed over its cage, used its tail well to wrap around things—bars, etc. When put on its chain to be taken over the *hurdle* it resisted and when placed on the first part of the *hurdle* made no effort to go through with the experiments. It was pulled through by means of the chain, but at the end it did not open any of the boxes and only when the box was opened did it then look for food. It went in the room without its chain and on the shelf or in its cage it would jump to my shoulder when I snapped my fingers. Other trials with this ringtail on the *hurdle* showed that it had completely lost that association. This animal lived for eleven weeks.

It should be mentioned that this animal showed a difference in its emotional reaction after the operation. It chattered and screamed a great deal when other animals approached it and when I put it on a chain it screamed and chattered sometimes for three or four minutes before it became accustomed to the lack of freedom. It chattered and screamed also when I approached it to make it jump to my shoulder although it did this very well.

The autopsy showed the lesion to be at the tips of both frontals.

IX. Monkey 7, male ringtail. About a year and a half old at time of operation. This animal was also taught to go through the *hurdles,* which it did immediately before the operation in an average time of sixteen seconds. Operation on both frontals. This ringtail also showed no motor disturbance after the operation. It jumped from a shelf or its cage to my shoulder with its accustomed surety, climbed up the cages and on the bars in the room, chairs, etc. It sat about, dressed the skin of another monkey as well as it did before the operation. It did not, however, seem to 'remember' the *hurdle* experiment. It also had to be pulled through boxes, over the ladder and at the end it did not attempt to pick food out of the food boxes. This animal seemed less active after the operation than before. It got 'rheumatism,' or at least the muscles of the leg became stiff and evidently painful about a month after the operation and I did not attempt to carry on the re-education of the animal after this time. The animal survived the operation about six months and the autopsy showed the lesion to be somewhat further back than

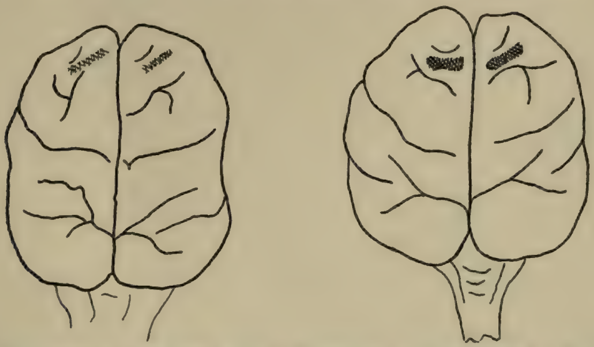

Fig. XI.—Diagrams of brains of male ringtails. A. Monkey 8 ; B. Monkey 7.

No. 8, but within the frontal areas. Both ringtails, it will be observed, lost their newly formed habits but retained the habits of earlier formation, namely that of jumping to my shoulder, which I had practiced with them for about seven months previous to the operation.

In this animal the lesion is in the neighborhood of both rudimentary fissures anterior to the precentral sulci, cutting off the extreme tips of both frontals.

X. Monkey 2. Female rhesus about a year old. This animal learned the *food box* experiment. Its memory was tested about three weeks later and found to be perfect. It was then operated upon in both frontals and the habit of the *food box* was lost. Following the operation I did not note any motor or sensory deficiencies and the animal seemed otherwise like a perfectly normal monkey and with little mental change. The mental change was that it was not so friendly as before and it chattered somewhat when strangers approached. When about in the cage with other monkeys, however, it got along well with them and after a time the difference in its behavior to what it had previously been was not so marked. This animal eventually relearned to open the food box and it unfortunately died at the time of the second operation. In this animal the first lesion was quite near but behind the precentral sulcus.

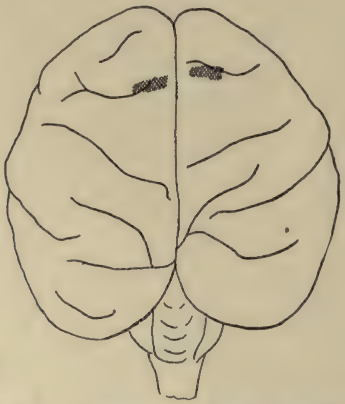

Fig. XII.—Diagram of brain of rhesus 2.

From these experiments, both on cats and monkeys, it is seen that the newly formed habits were lost. In several cases habits of longer standing were not lost. It might be supposed that one could conclude from these and other similar experiments that the frontal lobes are concerned with the production and the retention of simple sensory motor habits. A very valid objection, however, may be urged against considering the matter settled by these experiments alone. This objection is that the results may show only an inhibitory action. They may show only that the habits are lost whenever the integrity of the brain is destroyed and not whenever one portion of the brain is affected. Such a criticism is, however, equally potent against the results of Hitzig's and of Bianchi's experiments and of those of other investigators. Whether the loss of habits is due to the destruction of that part of the brain concerned in the mechanism of the simple habits or due to surgical shock is not decided by the experiments.

B. The Effect of Surgical Shock upon the Retention of Associations.—I think, however, that the following experiments demonstrate clearly that the loss of the habits in these cases is not due to surgical shock or to any other disturbance of the brain as a whole. In cats this is very evident and in the few experiments on monkeys it is indicated quite clearly.

Let us first consider the effect of the operation on an animal in which the operation was carried only up to the point of the destruction of brain tissue without actually touching the brain. In this experiment the animal was etherized as usual, the skull was trephined over the frontal lobes on both sides and the dura was cut. The brain was not injured. The scalp was then stitched together and the animal was observed.

XI. Cat 14. Active male, about 9 months old. This animal learned habit *string front*. The average time for the performance on the day of the operation was 2⅔ seconds. The operation was performed as described above. Fifteen minutes after the operation the cat walked about the room and tumbled about a bit, seemingly a trifle drunk from the anesthetic. No test of the memory was made on that day. Twenty-four hours after the operation the cat was placed in the *string front* box and gave the appropriate motor response as readily as before the operation. The average time in ten trials was 2½ sconds. No change in the behavior of the animal was noted from the time of the operation until it was killed five weeks later. At the autopsy the dura was found adherent at the skull and there had been an attempt at repair in the neighborhood of the "buttons." The brain was perfectly normal, uninjured about the point at which the trephine buttons had been taken.

Other similar experiments were performed and in none were the habits lost. They are a sufficient evidence, I believe, to show that the loss of the habits when the frontals are excised is not due to the general shock effects of the operation, the use of an anesthetic, the loss of blood, or even injury to the brain itself. Moreover, in these cases the animals were tested on the day succeeding the operation when the effects of shocks were greatest. Even under these adverse conditions the associations were always retained. In one monkey also I carried the operation up to the point of incising the brain tissue in a manner similar to that described in the preceding case. The result with this animal was the same as that with the cat. The day following the operation the habit was perfectly retained. Later cases will also be cited to show that even the operations on the frontal region and the shock effects from injury to the brain did not always bring about the loss of the associations. It is, therefore, proper to conclude that an operation as such has little or no influence upon the retention of these simple habits.

C. The Retention of Habits after Extirpation of Portions of the Cerebrum.—But the question may be asked, "May not the loss of the cerebral substance produce a greater nervous shock than in the cases just cited and may this not then explain the loss of the associations?"

XII. Cat 17. Active male, about six months old. This cat was practiced for *string front* and *string above* in which habits were perfect. In this animal a portion of the parietal was cut away from the underlying fibres, in extent about the same as I tried to cut away in the frontal region. This was taken in an area between that which gave a motor response on stimulation and the occipital region which is concerned with visual processes. For an hour after the operation the animal seemed weak and for the remainder of the day was restless. Three days after the operation the animal was tested to determine its retentiveness and it escaped from *string front* in an average time of $7^3/_5$ seconds, while before the operation it had opened the door in an average time of three seconds. With the *string above* on the day of and before the operation it escaped in an average time of $5^4/_5$ seconds, and on the third day after the average time for its escape was $9^1/_5$ seconds. About seven weeks later the whole of the right

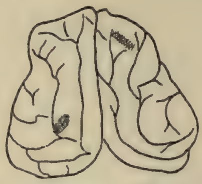

Fig. XIII.—Diagram of brain of cat 17.

frontal was excised. Two days before the operation it had escaped from *string front* in an average time of two seconds. Two days after the operation the average time of escape from this [illegible] seconds and three days later it averaged 32 seconds.

XIII. Cat 23. Female, ten months old. It had learned *string front* and *string above.* Both parietals were excised. Both associations were perfect before operation and three days subsequent to it. There were no motor defects and nothing of special interest was noted in this case. The animal was killed on the fourth day and the lesions were found to be about 8 mm. square.

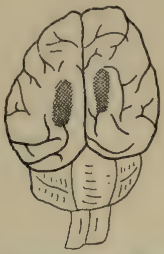

Fig. XIV.—Diagram of brain of cat 23.

XIV. Monkey 3. Male, pigtail (macacus nemestrinus), about a year and a half old. This animal was never very lively and had a peculiar waddling gait. His head and shoulders always seemed too large for his loins and legs. The other animals in the cage with him would pull his short tail and while he would look ferocious he would neither attack nor bite them. He was the buffoon of the family. He was easy to handle and did not resent the presence of strangers or other monkeys as some of the other animals did. This animal was practiced on the *food box* (55 trials) at which time he was able

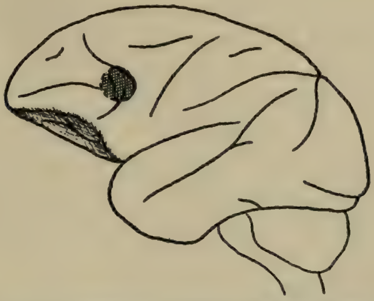

Fig. XV.—Diagram of brain of pigtail monkey 3.

to turn the button and get the food in an average time of about 1.2 seconds. Both frontals were separated from the other part of the brain and there was an uneventful recovery after the operation. The day following the operation he was quite lively, ate a pear eagerly and was inclined to be a trifle ugly, which was utterly unlike his previous behavior. He walked up and down his cage, turning about, and his attention was not attracted very easily. This activity continued for the following day and the wound or bandage evidently irritated him, for it was torn off at night. On the second day he was put into the cage, went to the food box immediately, turned the button, opened the door, but did not take the food until his attention was attracted to it by the experimenter. The average time in this experiment was 3.4 seconds. He continued to do the button experiment well from this time on. He became less active in about ten days after the operation and returned to his normal condition. At no time was there any lack of coordination in eating, walking, standing, or climbing. Vision and hearing seemed to be perfect and there was no change in the skin sensibility that I could determine. This animal caught flies after the operation as well as before. He died 6½ months after the operation. Cause of death unknown, possibly pneumonia.

The brain showed the lesion at the base of the upper frontal lobe just below the antero-superior turn of the precentral sulcus extending a little bit beyond and encroaching upon the precentral convolution. A diagram showing the left side of the brain is given in Figure XV.[1]

XV. Monkey 6. Male, macacque, about one year old. This animal was trained for 15 days over a period of 34 days, at the end of which time he obtained food from the *food box* in 1.8 seconds average. Both frontals were cut. There was little hemorrhage at the operation and the animal an hour after being taken from the operating table was lively, ate a banana and sugar. The following morning it was quite well but there was some oedema at the supraorbital depressions. It was very active, although it did not have the unceasing and aimless activities which characterized the pigtail just described. Two days after the operation, when put in the cage of the food box experiment, there was practically no hesitation about turning the button and opening the door, although the time taken for this was much longer than in the case of the previous animal. It averaged 23 seconds. Two days later it averaged 10.3 seconds.

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[1] This and other brains were given to Dr. C. B. Farrar to be examined more carefully and reported upon.

Later again, on the ninth day, it averaged 7.8 seconds. This animal had before the operation learned to take food in its mouth from my hand rather than, as most monkeys, to take it first in their own hands. This habit was also retained after the excision of the frontals but in this case there was no time taken either before or after the operation. In addition I had also taught this animal another trick which I used for getting the animal into the food cage. I had a box prepared on a frame which fitted the large cage in which some of the animals were kept. When this box was introduced into the cage, number 6 was usually the first to jump into the box. This association was not retained so well, although in this case I did not take the time for the performance of the act either before or after operation. After the operation the macacque would not get into this box and he had to be driven in as he had at the beginning of the experiments.

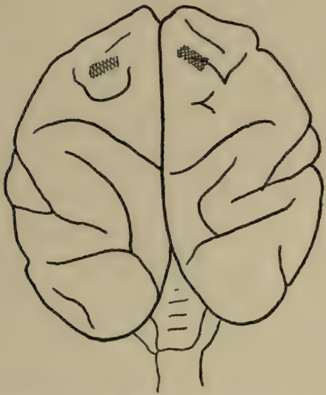
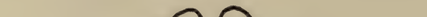


Fig. XVI.—Diagram of brain of monkey 6—macacque.

Both cases XIV and XV show a slowing of the time for the performance of the appropriate motor response in the case of the *food box*, and the macacque in addition showed the retention of one other habit and what was apparently the loss of a third. The slowing may be due to some disturbance of the tracts remotely concerned in the habit. This animal lived 15 months after the operation and during this period relearned, or, in the case of the food box, became more proficient in the habits than it was immediately after the operation. The animal was killed and on autopsy showed that the lesion on the right side was at and immediately above the precentral sulcus corresponding in position to the superior frontal in man, while that on the left side was somewhat anterior in position and corresponded more to the second frontal.

XVI. Monkey 11. Male rhesus about 18 months old. This animal learned *food box* and was practiced on 18 days over a total period of 43 days. The animal had thoroughly learned the habit in 9 days but it was further practiced until the reaction of opening the button took on the nature more like that of a reflex. So soon as the door of the box was closed it would immediately go to the button and turn it even before any food was placed in the box. Both frontals were removed and the attempt was made to make the cut rather far back in the frontal region without encroaching upon the motor zone.

On the day of the operation, 2½ hours after the animal was taken from the table, it appeared as bright and alert as it had previously been and ate sugar quite eagerly. Two hours later it was given bread and potato which it handled well. It drank water, putting its hands up to the cup without any indication of lack of coordination. It was let out in the room the following day, walked about, stood, climbed on the cages, and ate, all of these being performed in a perfectly normal manner. When put in the small cage by itself it walked up and down in front of the netting and was more active than it had previously been. In the *food box* cage it crawled into the food box, came out again, and repeated this a number of times. This animal had previously showed much signs of fear at a broom or a stick in the hands of those who approached it and this reaction of fear persisted after the operation and seemingly was the same as before. When put in the *food box* to test its retentiveness there seemed to be



no loss of the association. It went immediately to the button, turned it, and once when it turned this around too much it went at it again immediately and turned this again and again until it had got it in the right position. Even with this difficult attempt the average time of the first series after the operation was the same as that of the last series before the operation. The test of retentiveness was made two days after the operation. Two days later it opened the door in a less average time than it had immediately before the operation and after an interval of 14 days, in which no tests were made, the animal still retained a 'perfect memory' of this association. The activity of this animal gradually decreased and in about ten days it was perfectly normal so far as could be determined. Observers who saw the animal at that time and later in a cage with other monkeys could notice no difference. A diagram of the brain is given in Fig. XVII. The site of the lesion in the right hemisphere occupies the base of the upper frontal and is bounded above by the anterior turn of the precentral fissure, below by the inferior frontal fissure. On the left side the lesion was a little higher than in the right hemisphere. It occupies the base of the upper frontal and crosses the upper part of the precentral sulcus, encroaching upon the superior third of the precentral convolution. The animal had lived for a period of 7½ months following the operation.

XVII. Monkey 17. Female rhesus, about a year old at the time the experiments were started. This animal learned the *food box* after about thirty trials so that it opened the door in an average time of 2.2 seconds. It was further practiced for some days and at the end of 25 days no further trials were made for 161 days. At the end of this time the animal showed almost perfect retentiveness and surety in its movements in opening the door of the box to get its food. This animal opened the door just before this long interval in an average time for the last two days of 3 seconds and after the interval the average time for six days was 2.6 seconds. Other intervals of 16, 10, and 5 days were then given interspersed between the days on which the animal was trained. At the end of this time for the last five days before the operation the average time for opening the box was 1.6 seconds.

Both frontals were cut away from the remainder of the cerebrum at one operation. A half hour afterwards the animal made movements of intimidation, that is, she opened her mouth and projected her head forward and endeavored, as she previously had done, to frighten the spectators. Two hours after the operation the effect of the anesthetic (A.C.E.) had disappeared. She moved about well and on the following day she walked, jumped and climbed with her accustomed ease. She ate from her hand and took a cup of water as well as she had previous to the operation. Two days after the operation she seemed a little stupid and did not appear to have as much fear of me as she usually had shown, although she started if a quick movement was made towards her. Coordination was perfect. She picked things up with her hands from the cage and small particles of food which were there were seen by her and picked up in the fingers and carried to her mouth. Some ravelings from the bandage hung down about her mouth and often were pushed into the mouth with food. She did not seem disturbed about this until they became quite numerous and then she picked them out of her mouth, throwing them to one side and then repeating the operation after they got in her mouth again with other food which she placed there.

Snapping of the fingers and whistling attracted her attention. When put in the food box she immediately turned to the door and hit the button, but seemingly at random. She also, like number 11, crawled in and out of the food box from the larger cage, going in and out a number of times. When the door of the food box was kept open she looked into the box a number of times. This was not as it had been before the operation. In five trials on this day the animal opened the box in an average time of 1.8 seconds. Later experiments gave a similar result and showed that the sensory motor habit had been well retained. Figure XVIII shows the brain lesions in the case of monkey 17. The cut on the right side was in the prefrontal region anterior to the precentral fissure about the second frontal convolution. That on the right was a trifle behind, also in the middle frontal convolution.

The last four experiments coupled with those which were previously described on cats indicate clearly that the loss of association in animals consecutive to lesions in the frontal regions is not due to the general shock effects of the operation. In these cases the frontals were excised, or at least they were cut, so that if this region be one in which the shock effect is more readily produced we should expect the last four animals to have lost associations.

These animals that have given results unlike those which were found with the other monkeys and with cats were trained over a longer period than most of the animals which I employed. In these cases the response in the associations took on the character of the reflex act and it is possible that the association of the sensory and motor impulses did not take place through the intermediary of the frontal lobes or of any part of the cerebral cortex exclusively. We know that in man habits are formed by the activity of the cortex, but when the paths for these habits become well worn, possibly, perhaps probably, shorter by-paths are established in lower centers. I think that in these four monkeys, Cases XIV, XV, XVI, and XVII, where the association had become more like a reflex, the association tracts were not so generally used and that lower centers were more concerned in the coordination or union of the sensory and motor elements of the association. Two of the animals, it is to be observed, give a slowing in the time for the performance of the trick and it is possible that in these animals, which were not so well trained as monkeys 11 and 17, the lower tracts had not attained their full functional efficiency.

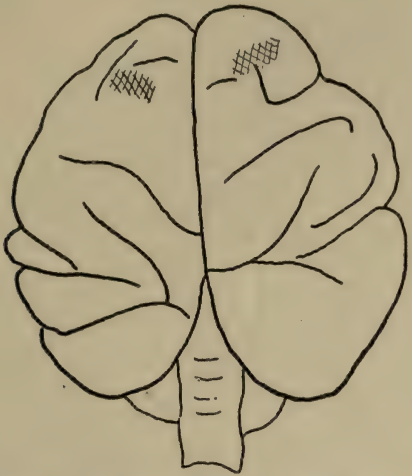


Fig. XVIII.—Diagram of brain of monkey 17, rhesus.

A crucial experiment which would determine this I have not yet had time to do. This experiment will be performed as follows: I shall take an animal in which one of the associations has been formed and become of the nature of a reflex and in the same animal in a period of 4 or 5 days get it to acquire another association. The operation in such a case would show whether the association of long standing was greatly affected or more affected than those which were recently formed. In the cats whose cases I have described above it was noted that long standing habits, as coming to a call, etc., were not lost, although the more recently formed ones in the *button, string front* and *string above* were lost. The two ringtails, VIII and IX, had not lost the habit of jumping to my shoulder although the other associations which were more recently formed were lost. The male macacque (number 6, case XV), which showed a decided retardation in the time of opening the food box, and perhaps also loss of the habit for the capture cage, retained perfectly so far as could be determined (no time was taken as mentioned above), the habit of taking food in its mouth from my hand rather than taking it first in its own hand as all of the other monkeys did. Other monkeys, notably case VII, retained the association of getting into the capture cage, although the latter monkey did not retain the other associations.

The facts which have just been cited regarding the retention of older associations and the partial or complete loss of the newly formed ones are indicative that the retention in cases XVI and XVII is most likely due to the fact that the associations in these cases were very well established and had been practiced over comparatively long intervals of time. I shall, however, at a later time, take up this matter in more detail.

The removal of one frontal does not always occasion the loss of habits. The following case illustrates this and also indicates that the destruction of two areas corresponding in size to the frontals does not produce loss of habits.

XVIII. Cat 35. Male, 5 to 6 months old. This cat was somewhat sluggish in its movements and the time of escape from the boxes was much longer than other cats. It learned *string front.* The right frontal and the left occipital lobes were then excised. The day following the operation there was no effect noticeable. So far as I could determine there was no defect in the visual fields of the animal. The animal could see food brought in from any quarter of the visual field. The animal was quiet and in the motor sphere the same after this operation as before. There was a quick recovery and on the day following the operation the time for escape from the box averaged 8 seconds as compared with 5.4 seconds on the day previous to the operation. A month later the left frontal was extirpated. Fifteen minutes after the operation the cat walked well but seemed dazed, probably from the ether. It seemed intelligent and bright on the succeeding days, but occasional periods of apathy were noted which had not characterized the animal after the previous operation. Three days after the extirpation of the left frontal it was tested in the *string front* and again on the fourth day, but both times failed to open the box in the two minutes which were allowed. Its activity in the cage was considerable, although its movements were normally sluggish and its appearance in *string front* was very much like that of an animal that had not been placed in the box before. It did not direct its movements against the door or the bars and it paid no attention to the cord which it had previously attacked exclusively after its training. The movements at first were the random movements of a cat trying to escape from confinement. Eventually it hit upon the proper movement and slowly regained the habit (see below, case XXII).

D. Formation of Associations after Removal of Both Frontal Lobes.—The results of the experiments which have so far been recorded indicate that the frontal lobes are concerned in the production and retention of simple sensory-motor habits and that habits which are recently learned are lost after the removal of the frontals. This loss cannot be accounted for on the basis of a shock effect, nor does it seem probable that it can be accounted for on the basis of the removal of brain substance regardless of the position at which the extirpation was made. Cat 23 (case XIII) shows clearly that at any rate the latter statement is true for cats. Moreover, cat 35, in which the right frontal and the left occipital were excised, retained the habit of *string front* after the operation. It would be reasonable to suppose, if the frontals are concerned in the production of these habits, that such association could not be formed after the removal of these portions of the hemispheres. Several cases of cats and some of monkeys show, however, that after the removal of the frontals there is a possibility of the acquirement of habit by these animals.

XIX. Cat 6. Very active female, about four months old. This animal was operated upon before any habits had been formed. Both frontals were cut away from the rest of the cerebrum and three days later, when allowed to roam around the room, it appeared to be normal. When held up in front of the cage of mice it showed well-marked emotional reaction. Two weeks after the operation the cat was placed in *string front* and the habit of opening this box was fully formed after 25 experiments. The animal was tested over a period of eleven days, and it seemed that the curve of learning in this animal was about the same as that in an animal before the removal of the frontals. The animal was killed two weeks after the experiments began and an examination of the brain showed that on both sides

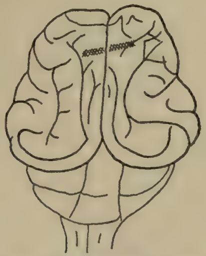


Fig. XIX.—Diagram of brain of cat 6.

the lesion was posterior to the crucial sulcus and very close to the motor zone. The left side lesion was somewhat more posterior than that on the right. From the time of the operation until its death no motor or sensory disturbances were found.

XX. Cat 7. Active female, 9 months old. No associations were formed before the operation of removal of both frontals. After the operation the cat was very lively during the succeeding days and showed no lack of general intelligence, and nothing unusual was noted in the animal's behavior. The emotional reaction, when held before the cage of mice, was not very great before the operation and was about the same after. This animal learned the habit of *button* in three days. The animal was killed three weeks later and the brain showed that the lesions in this case were anterior to the crucial sulcus, the right being slightly in advance of that on the left.

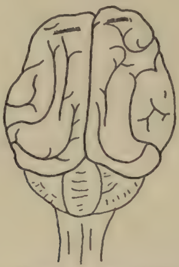


Fig. XX.—Diagram of brain of cat 7.

It has already been noted that in some cases the animal relearned habits which had been lost as the result of an operation. In one case a cat had lost the habit of *string front* after the operation and this habit was slowly relearned. In another animal, cat 11, the animal had learned the *button* and this animal lost the habit following the operation on both frontals. It learned it again and a second operation somewhat posterior to the position of the first resulted in the loss of the habit which it had relearned. A second time the animal relearned the habit and at that time the relearning evidently took longer than either the first learning or the first relearning.

XXI. Cat 11 (see also case IV). Female, about 9 months old. This animal had learned the *button*. After the first operation there was a loss of this habit. About two and a half weeks succeeding the first operation the animal was practiced and relearned the habit of *button*. A second operation was then performed, and the cut was made posterior to the one made at the first operation. For ten days succeeding the operation there was no evidence (judging by the lack of response in two minutes) of the persistence of the association. Two days after the operation, when placed in the box, the cat walked up and down, then looked in and out between the bars but made no attempts to claw at the button or to get out. At times it stopped in its walk and looked steadily at some other cats in a near-by cage. It did not go passively into the box when I put it in as it used to do, but it tried to prevent this by scratching when I attempted to put it in. Smell was present. Movements of walking were fully coordinated and it jumped well from a box to the floor. It did not, however, stand on its hind legs with any degree of stability when food was held up before it, but as I had not tested this previous to the operation I cannot be sure that this was due to the operation. It seemed that there was a slight anesthesia of the forepaws. There was a normal response when held in front of a cage of mice.

When fish was placed outside the box and the cat inside, the animal did not attend to anything but the food. There was no attempt made at first to move the button and it was only slowly that the association was relearned. Fig. VII gives a diagram of this animal's brain and it is noticed that the lesions were posterior to the supraorbital fissure. In the diagram no distinction is made between those of the first operation and those of the second. In this case the part extirpated is well within the prefrontal area.

XXII. Cat 35. This animal also learned the habit which had previously been lost after the removal of both frontals. The first operation in this animal as described above (case XVIII) was the destruction of the right frontal and left occipital lobes. The animal had previously learned *string front* and after the operation it opened the door of this box in an average time of 8 seconds as compared with 5.4 seconds previously. Four days after the operation the average time for opening the box was 3.8 seconds. The animal was then practiced on the habit and a month after the first operation the left

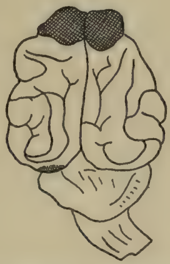


Fig. XXI.—Diagram of brain of cat 35. This shows by cross-hatching a certain amount of cerebral hernia resulting from the two operations.

frontal was excised. There was failure to open the door after the second operation and the animal only slowly relearned the secret of the *string front*. The first day after the second operation in which it began to relearn the association the average time for opening the box was 163 seconds and it took the animal 35 experiments before it could open the box in as short a time as it had done previous to the operation.

XXIII. Female rhesus 22. This animal had lost its habits after the removal of both frontals but regained them during 52 days succeeding this operation. In this case the animal seemed to take about the same length of time as it had taken during the first period of education on the food box and there was nothing striking in the results other than that which has already been described in the case of the cats. This animal died as the result of a second operation before its memory could be tested (see case VII). A similar result was obtained with monkey 2 (case X.).

These results (cases XIX, XX, XXI, XXII, and XXIII) are of considerable interest in that they show that while the frontal lobes are normally concerned in the production and retention of simple sensory motor habits, there is a possibility of acquiring new associations after the removal of parts of the frontals. We know that in man following the destruction of the frontal regions, which to him are probably of more value and of greater importance because of their greater development, the effects are not very marked unless the destruction has been sudden and the other portions of the brain have not adjusted themselves to the loss of these association areas. That one frontal may be sufficient and may be removed without any marked intellectual change is noticed from the results which have been collected by Schuster, Müller, Welt, and Phelps. We also know that if the third frontal convolution on the left side is injured or destroyed it is possible for the right third frontal to take up the functions which are normally assumed by that portion of the left hemisphere. It seems probable to me, therefore, *A*, that in the cases which have just been described the loss of the associations after the first operation was due to the destruction or to the severing of the connection of the brain parts which were intimately concerned in the association but *B*, that other portions of the brain could take up the function and *C*, that the region of the frontals which had not been disturbed took up the function of the association of the motor and sensory elements in the new formation of the habits. In the animals in which the second operation was successfully performed it resulted in a loss of the habit which had been re-formed and this indicates that the frontal lobes probably, at their posterior limit had taken up the associative function in these cats.

E. Emotional Condition of Animals from which the Frontal Lobes Have Been Removed.—In the preceding account of the behavior of animals before and after the operations I have noted that the emotional reactions were the same after as before the removal of the frontal lobes. All the cats that showed emotional reflexes when held in front of the cage of mice before the operation were similarly affected after it. After the removal of the frontals several cats showed evidences of displeasure when handled roughly and there was indication of 'feeling' when unusual noises were made. All the cats were as friendly as before, with the possible exception of one animal. A few that tried repeatedly to escape from me before the operation kept close to me afterward and we might say that they were more friendly. Whenever I was among them after the operation the animals were continually brushing against my legs and purring as good-natured cats do, and that was more marked after the operation.

Among the monkeys there was no marked difference in the emotional response. Some of the monkeys showed signs of displeasure when one approached too near the cage in which they were kept and these animals continued to be unfriendly after the operation. On the other hand, only one animal seemed more afraid after than before.

So far as these observations may be stated in general terms, I should say that the emotions remain practically the same after as before the operation but that any change present, particularly in cats, was a change to a greater friendliness. These experiments do not help toward the solution of any problem of the emotions so far as I can see. They indicate only that the emotional reactions were present or lacking in these individual cases. Here we cannot differentiate between the emotion proper and the emotional reaction, and it is consequently difficult and, in fact, impossible to say that the emotions were unchanged. All we are justified in concluding is that the reaction remained the same; the emotion may or may not have been different.

F. Nutrition of Animals from which the Frontal Lobes Have Been Removed.—Most of the cats which I used died of distemper. Two had been affected with mange some time before death and in none of the cats did treatment for these diseases seem to be efficacious. Of the cats at post-mortem all but one were found to be greatly emaciated, although, in general, the appetite for food was unusually good. The feces seemed normal but no special test of this or of the urine was made and I have no data beyond these general observations to indicate any special metabolic disorder. The monkeys did not show any great change in appetite or in nutrition and in these cases also I have not had the excretions examined. The results obtained with cats would lead us to believe that the frontal lobes may be concerned somehow with the processes of metabolism and this would agree with the findings of Langelaan and Beyerman on the respiratory function, which have previously been discussed. My results with monkeys would agree with the experiments of Ferrier with monkeys and they disagree with those of cat experiments which have been performed by me and which have been confirmed by Langelaan.[1] Ferrier found that in monkeys there were greater changes in the nutrition of the body after the lesions of the occipital lobes and that there were little or no changes after the extirpation of the frontals.

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[1] Private communication.

V. SUMMARY AND CONCLUSIONS

A. In monkeys and cats the frontal lobes are normally employed in the formation of simple associations.

B. When the frontal lobes are destroyed recently formed habits are lost. This result was found in cases I, II, III, IV, V, VI, VII, VIII, IX, X and XVIII.

C. The loss of the associations is not brought about by lesions of other portions of the brain, XI, XII, XIII, and XVIII.

D. The loss of the associations is not due to shock, for lesions of other parts of the brain are not followed by loss of habit nor does the anesthetic and loss of blood, etc., produce loss of associations, XI.

E. Unilateral lesions of the frontal areas are not followed by a loss, but there may be a slowing or retardation of the motor response, XVIII.

F. Habits once lost after removal of the frontals may be relearned. The relearning takes about as long a time as if the animal were learning a new association, X, XIX, XX, XXI, XXII and XXIII.

H. Only newly formed habits seemed to be lost after such lesions. Long-standing habits seemed to be retained. I, IV, VIII, and IX.

I. The emotional condition of the animal remains the same after as before the removal of the frontals.

J. Emaciation and liability to disease were noted in all cats from which the frontals were extirpated, but in the monkeys this was not at all marked, some animals remaining alive for long periods and some of them having to be killed for the purpose of autopsies.

The experiments which have been described and the results which have been obtained have, I think, value other than that of indicating the functions of parts of the association areas in animals. They indicate that for the determination of the disturbances coincident with lesions in the association areas better methods of diagnosis and experiment are needed. The experiments show not only that there are changes coincident with lesions or disturbances of the frontal lobes but that the associational loss is one that could not be determined by simple observational methods. The results suggest, furthermore, that for the determination of functional changes in man consecutive to and resulting from injuries to the associational areas accurate physiological and psychological methods should be employed. Clinicians have developed the methods for the determination of the changes in speech ability that occur when the left third frontal convolution is injured or when the temporal lobes are affected.

These methods give accurate information regarding the presence or absence in an individual of the faculty of speech. For the other associational areas accurate methods have not been employed by the clinicians nor have the physiologists been able to advance our knowledge of the functions of these portions of the cerebrum.

Both the clinical and the physiological evidence points to a dependence of certain mental processes on the integrity of the frontal lobes and, in fact, on the integrity of the brain as a whole. From a general consideration of the collected cases and the results of the physiological experiments I am inclined to think that the frontal or prefrontal areas are of great value in our mental life. I am not ready to accept the hypothesis of 'attention' or 'inhibition' as accounting for all the facts which have been gathered relative to the frontal areas. There is at the present time great need for more careful psychological examination and experiment in the hospitals where alone patients with injuries to the brain are to be seen. We are all interested in the functions of the brains of animals largely because of their value in determining or indicating the functions in man, and the strength of the clinical work is that the observations are made on man. On the other hand, the weakness of the clinical work is that too much is claimed without adequate analysis of the mental conditions of the patients. Much more and much better information could be gathered if the patients were tested along lines which are followed in the psychological laboratories of universities or of insane hospitals.

From the clinical and experimental results of others as well as those which have been recorded in the present paper I conclude that the frontal lobes are concerned in normal and daily associational processes and that through them we are enabled to form habits and, in general, to learn.

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